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SOVIET INSTRUMENTATION AND
CONTROL TRANSLATION SERIES

Measurement Techniques

(The Soviet Journal *Izmeritel'naia Tekhnika* in English Translation)

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SUPERVISION OF MEASUREMENT IN RURAL DISTRICTS

A. S. Kovekhov and L. Sh. Vinderman

Temporary departments have formed the basis for state control over measures and measuring devices in rural districts. However, in the reorganization of the work of the local branches of the Committee on Standards, Measures and Measuring Devices, the organization and operation methods of the temporary departments will have to be changed.

Obviously, the departmental role in technical supervision of measures and measuring devices has grown considerably under the new system. One of the existing problems is to take care of all the measuring apparatus used by means of departmental or state supervision. With this aim in mind, the oblizpolkom, acting upon the suggestion of the Chernovitsy state control laboratory for measuring techniques, decided to organize a network of departmental supervision over measures and measuring devices and to organize a revision of diversified apparatus in 1958-1960. This made it possible to check, under departmental or state supervision, almost all of the measuring devices generally used in the rural districts of the department during the first half of 1958.

A scale repair shop had been set up some years ago in the Chernovitsy district in association with the Sadgorsk MTS; this shop repaired and checked weights and scales in the kolkhoz and the MTS. This repair shop contributed a great deal to an orderly organization of kolkhoz measuring techniques.

The scale repair shop at the Sadgorsk MTS was unable, however, to fulfill demands of the kolkohz and the RTS because of its organization and its techniques. Therefore, at the suggestion of the GKL, the shop was transformed into a base laboratory for the district agricultural management; this laboratory was responsible for the control of measuring devices used by the kolkhoz and the RTS, and had to carry out periodic departmental checks of the apparatus. The base laboratory of the regional agricultural management also repaired the measures and measuring devices, but its basic function was to carry out departmental supervision over the means of measurement. Mobile laboratories were set up under the jurisdiction of the base laboratory with two units to carry out periodic checks and repairs on the apparatus used in the kolkhoz and the RTS, these checks and repairs to be carried out directly on the spot where the apparatus was used. A special group was created for the control and supervision of the means of measurement, without having the responsibility for repairs. The base laboratory obtained standard manometers and was given the right to carry out compulsory inspections of the manometers in the kolkhoz and the RTS.

Acting on the decision of the oblizpolkom, the Chernovitsy scale repairing factory undertook a technical supervision of measuring devices used in various institutions and enterprises. In order to carry out technical supervision of the means of measurement, the factory was assigned two automobiles. The technical supervision group, which did not handle repairs, was also strengthened. In accordance with oblizpolkom directives, all regional enterprises would sign contracts with the scale repair factory for technical supervision services. The cost of this technical supervision service was established by the oblizpolkom.

Supervision included not only the checking of the apparatus, but also a series of other services: cleaning, replacement of small parts, simple regulating, touching up, reconditioning, etc.

District supervision of measuring devices was carried out twice a year; the first inspection was synchronized with that of the temporary department. Two or three weeks before the temporary department started operations, brigades from the base laboratory of the district agricultural management and the scale repair factory went out into the field in mobile laboratories and carried out a check of all the measuring devices widely used in the district,

introduced reliable means of measurement not subject to state control, checked reliable means of measurement which are subject to state control, send such apparatus away for repairs as could not be repaired on the spot and eliminated minor defects during the process of inspection. The government inspector visited the region group by group and enterprise by enterprise,and carried out a check and control of measuring devices,as well as of the activities of the brigades.

This organization of a temporary department seems most effective and takes no more time than that of an ordinary temporary department.

A survey of the groups within the region made by a government inspector takes even less time. In the future, when the quality of the checks carried out by departmental supervising agency branches are improved, the inspection of measuring devices will be left entirely up to these organs and will thus shorten by one-third the time given to this work by the temporary departments.

In the Vashkov region an experiment was carried out; the supervising brigade from the scale repair factory did not go out into the field before the opening of the temporary department,and the government inspector and the scale foreman visited the region together. The scale foreman in the presence of the government inspector took care of the minor defects in the apparatus for a certain sum. This method was not particularly successful as the inspector had considerable time left on his hands.

All the regional districts are under the supervision of reliable government inspectors.

The second periodic check of the regional apparatus carried out by the supervisory brigades is scheduled depending on the time and duration of the temporary department checks. It is evident that the number of devices to be repaired will decrease in a period of 2-3 years, because minor defects will be taken care of on the spot and with a bi-annual inspection major defects will be encountered less often.

After the work of the temporary department has been completed, the government inspector sends a report of the results to the regional ispolkom. A number of regional ispolkoms recommended a systematic maintenance of measurement technology devices within the region. Government inspectors make periodic checks to see that the recommendations of the regional ispolkom have been properly carried out by the regional enterprises.

The new system of carrying out the work of the temporary departments will guarantee the maintenance in good condition of all measuring devices.

NEW MEANS OF SUPERVISION AS INTRODUCED IN THE UPPER-KHORTITSK DISTRICT OF THE ZAPOROZHSK REGION

Ia. A. Zil'ber

During the second quarter of 1958 the Zaporozhsk State Control Laboratory of measuring techniques began plans for a revision of the operation methods of state supervision.

The Upper-Khortitsk region was chosen for the experiment.

The regional ispolkom issued a directive for carrying out the state checks and repairs of apparatus on the spot where used. In order to do this, the scale repair factory sent out a brigade with a car completely equipped with necessary standard devices. The head of the department, together with the scale foremen, visited the regional enterprises.

In order to get the measurement devices ready for the inspection campaign, they were first checked by the kolkhoz and the sovkhoz.

When the brigade arrived, a representative of the kolkhoz (usually a mechanic) was appointed to take care of the brigade needs, provide them with necessary information and sign the proper contracts for technical services rendered.

While the brigade was operating, the mechanic was being instructed in,and introduced to,the practical use, operation and maintenance of the devices (regulation of the scales and milk gages, taking apart and transporting of apparatus, care and cleaning of the apparatus, etc.).

The brigade published in a special journal the names of the kolkhoz or enterprise, data on the apparatus (serial number, measurement limit, condition, etc.). The journal noted the results of the apparatus check.

The foreman carried out, together with the government inspector, a technical inspection and supervised current repairs; state inspection followed. If the apparatus conformed to the instructions of the Committee on Standards, Measures and Measuring Devices, it received the state seal of approval.

In the case of apparatus which was in need of regulating and repairs, the inspector wrote out a memorandum to the chairman of the kolkhoz suggesting that the apparatus be sent to the regional scale repair machine shop,or, if the number of defective devices in the kolkhoz and in the neighboring kolkhoz was large, to send them to the nearest kolkhoz where the mobile brigade was operating. Repairs were carried out within 3 or 4 days after the kolkhoz had been visited.

During the second quarter of 1958 this type of control was carried out in all 14 kolkhoz, one sovkhoz and one agricultural branch in the district; also at the hospital, the drug store and in 2 branch divisions. A total of 1462 devices was inspected, 979 approved on the spot and 483 approved upon repair. Out of 38 automobile scales and 199 unequal-armed mobile scales, 26 automobile scales and 123 unequal-armed mobile scales were approved on inspection or after immediate on-the-spot repairs. Only 12 automobile scales and 76 unequal-armed mobile scales needed major repairs.

As a result of such work not a single defective device remained in the organizations visited by the brigade and all the kolkhoz, sovkhoz and agricultural branches were ready for the inspection campaign.

This work was carried out in other organizations during the third quarter.

The kolkhoz chairmen and enterprise directors were very pleased with this type of operation, for the measurement devices did not have to be sent away for long periods of time to the regional center for checks and repairs. With this new type of operation it is possible to establish on the spot the need for a check of measures and measuring devices.

INTRODUCTION OF NEW MEASUREMENT TECHNOLOGY IN ENTERPRISES

As tried by the Zaporozhsk State Control Laboratory for Measurement Technology

D. M. Sizov

The Zaporozhsk GKL has given considerable attention to the introduction of new measuring techniques.

All the GKL workers, together with other planners, have taken part in this work, planned quarterly. Information bulletins furnished the GKL by the Committee on Standards, Measures and Measuring Devices have been very helpful. These information bulletins are distributed, according to the type of work done, to the various enterprises of the region. During the first half of 1958, the laboratory sent out 279 information bulletins to 34 regional enterprises. The bulletins indicate, as far as possible, which factory produces the apparatus described.

The laboratory has organized an information center, where one can find catalogues of apparatus, information bulletins, and the journals "Measurement Techniques" and "Standardization."

When measuring means are inspected and technical conditions checked so that they conform to GOST, and when state inspections are carried out, laboratory workers find out where the out-of-date equipment is being used and can all make suggestions as to its replacement by modern devices.

Thus, at the metallurgical factories many mechanical potentiometers have been replaced by electronic ones; electron meters have been obtained and analytical scales of antiquated and foreign construction have been replaced by the best scales of the ADV-200 type.

Nonlinear scale meters of the old INI-10 type have been replaced by the new INI-11 type at the Zaporozhsk factory.

The Zaporozhsk gorpishchetorg has practically eliminated all of the ordinary table scales and has replaced them by table dial-type scales VNTs-10 and VNTs-2.

All water graduates have been replaced by auto-saturators of the AS-type and syrup dosors of the PDSA-type.

Regional supervisors have helped greatly to introduce the new measuring techniques of the state control laboratory.

In order to help the workers with the regional supervision of enterprises, the laboratory conducts regional technical conferences for an exchange of information and also organizes seminars on various aspects of measurement or on special questions of apparatus nomenclature.

The laboratory also publishes a technical information bulletin for the exchange of information and for the development of measuring technology in various enterprises; it also helps organize regional supervision. Supervisory group workers have played an active part in the creation of this bulletin. The bulletin is sent to all basic establishments of the region.

In order to improve the inspections and in order to introduce new methods of apparatus inspection, the state laboratory has turned over to 17 establishments plans and sketches of various appliances and devices for the checking of apparatus, naming the factories which manufacture them.

The laboratory has also a special journal, which notes enterprises having received the sketches and diagrams, those which should receive them, and describes the devices produced.

During the first half of 1958, 16 enterprises produced different devices: devices for checking internal calipers, indicators, large standing calipers, devices for determining the measuring force of micrometers, for checking parallelism in micrometers whose limits of measurement exceed 11 mm, for recording apparatus diagrams, for checking the go—no-go meters whose limit of measuring exceeds 25 mm, oxygen manometers, etc.

ON THE QUALITY EVALUATION OF METHODS FOR CHECKING MEASUREMENT INSTRUMENTS

I. V. Dunin-Barkovskii and A. N. Karpasheva

As is known, the basic task of the testing and checking of measurement instruments, is that of verifying certain given properties of the latter and, primarily, their accuracy.

In practice, one or another method of checking is applied, which is selected from several methods, often on the strength of either subjective views of the performers or other chance circumstances. Therefore, it often happens that the checking of instruments of the same type is done in different ways. Basically, an objective criterion for the evaluation of the quality of a checking method is still lacking. In particular, this refers to such an important characteristic of the method-quality as reliability with respect to the basic metrological characteristics as provided by the method.

Such a situation is to a considerable extent explained by the fact that mainly long-established views have been applied in metrological practice until present times. However, modern statistical mathematics provide a much more perfect tool, making it possible to come close to the solution to such an important problem as the comparison of methods for checking measurement instruments with respect to their reliability according to objective, scientifically-founded criteria.

Insofar as the reliability in which we are interested can be quantitatively measured by probability indices, such a possibility appears, in particular, by using the theory of resolving functions and by the analysis of "operative characteristics" inherent in the methods. The latter method of the theory of verification of statistical hypotheses has been widely recognized in present times and it has been widely applied in the solution of many very important practical problems (statistical methods of analysis of various systems, statistical methods of control, etc.).

In order to clarify the possibilities of using operative characteristics with the aim of obtaining an objective criterion of the suitability of various methods for checking measuring instruments, let us consider some concrete examples.

In the majority of lever-mechanical measuring instruments, according to the standing instructions of the Committee for Standards, Measures, and Measuring Instruments, the control of errors in readings is done at several separate points of the scale, where, if the error in readings at any point of the scale is equal to or less than the allowable error by a quantity not exceeding the variation in readings of the given instrument, additional taking of readings is performed three times. The instrument is accepted as suitable if the deviations found by this procedure do not exceed the allowable values.

The limiting value of reading errors Δ_{lim} of the instrument is usually considered as the triple mean square deviation of errors in readings for the normal law of their distribution:

$$\Delta_{lim}=3\sigma. \tag{1}$$

In other words, the error which is accepted as the limiting error, is the one for which the probability P of obtaining errors smaller than this value is equal to 0.9973, i.e.,

$$P(|x|<\Delta_{lim})=0.9973, \tag{2}$$

where $\underline{x}$ is the reading error of the instrument (deviation of the readings from the actual value of the measured magnitude).

It follows from (2) that the probability that any single reading error of the instrument will exceed the value Δ_{lim} is equal to 0.0027, i.e., it is so small that reading errors larger than Δ_{lim} will almost surely not be encountered in practice.

The verified instrument will satisfy the technical requirements if

$$\Delta_{lim}\leqslant[\Delta_{lim}]. \tag{3}$$

i.e., if its maximum error does not exceed the allowable value. However, naturally, two problems arise here: with what degree of reliability (probability), with positive results of instrument checking, can it be ascertained that the limiting error of its readings will not exceed the allowable value in practice, and in what manner should the checking method be changed so that the probability of satisfying the indicated condition would not be less than the given probability.

Somewhat simplifying the problem, we shall consider the reliability of the method of evaluating the reading error at only one point, which is applied in practice, leaving, for the moment, the question of systematic

errors of the scale, and assuming that the indication errors of the instrument are subject to the normal law of probability distribution.

The verification of instrument indication errors can be obviously reduced to the verification of the statistical hypothesis that 99.7% of the central interval $(a - 3\sigma, a + 3\sigma)$ of normal distribution lies entirely in the given interval $(-\Delta, \Delta)$, where $\underline{a}$ is the abscissa of the center of scattering of instrument indication errors, σ is their mean square deviation, and $\Delta = [\Delta_{lim}]$ is the allowable value of the limiting inaccuracy of readings.

Figure 1 shows one of the possible mutual positions of intervals $(a - 3\sigma, a + 3\sigma)$ and $(-\Delta, \Delta)$ for $3\sigma < \Delta$, i.e., when the checked instrument is in good condition.

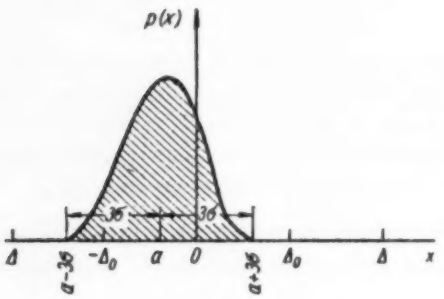

Fig. 1

The least favorable for the verification of the hypothesis N will be such a mutual position of our intervals for which point O of the verified scale, lying in the middle of the interval $(-\Delta, \Delta)$, will coincide with the center $\underline{a}$ of scattering of instrument indications, as in this case, if the instrument is unsuitable, i.e., for $\Delta_{lim} > [\Delta_{lim}]$, any of the readings falling outside the interval $(-\Delta, \Delta)$ will have the least chances and by this fact negate the hypothesis N, i.e., the instrument will be rejected. Let the method of verifying the hypothesis N (in other words, the method of checking the instrument indication errors) consist of the following:

1. n_1 examinations are performed (assuming the stopping of the movable leg of the lever catch), where:

a) if all n_1 observations lie in the narrowed interval $(-\Delta_0, \Delta_0)$, where $\Delta_0 < \Delta$ (in practice, for the majority of instruments, $\Delta_0 = \frac{\Delta}{2}$), the hypothesis is accepted;

b) if even a single observation (deviation of the instrument reading from the "actual" dimension of the measured object) exceeds the limits of $\pm\Delta$, the hypothesis is rejected;

c) if, from n_1 observations, even a single one is outside the limits of the narrowed interval, but all n_1 observations are in the interval $(-\Delta, \Delta)$, the observations are continued;

2. In the case c), additional n_2 observations are performed, where:

a) if all n_2 observations lie in the interval $(-\Delta, \Delta)$, the hypothesis is accepted;

b) if even a single observation lies outside of this interval, the hypothesis is rejected.

Let us find the operative curve for the given method of the hypothesis verification.

Let us denote by P_0 the probability that the result of one observation will fall within the interval $(-\Delta_0, \Delta_0)$ and by P, the probability that it will fall within the interval $(-\Delta, \Delta)$.

With the independence of examinations, on the basis of the multiplication rule, the probability that all n_1 observations will fall within the intervals $(-\Delta_0, \Delta_0)$ and $(-\Delta, \Delta)$ are equal to $P_0^{n_1}$ and P^{n_1}, respectively. The probability that all n_1 observations will fall within the interval $(-\Delta, \Delta)$, but that at least one of them will be outside the interval $(-\Delta_0, \Delta_0)$, is equal to the difference $P^{n_1} - P_0^{n_1}$, as the falling of all n_1 observations within the interval $(-\Delta, \Delta)$ represents the sum of two incompatible events:

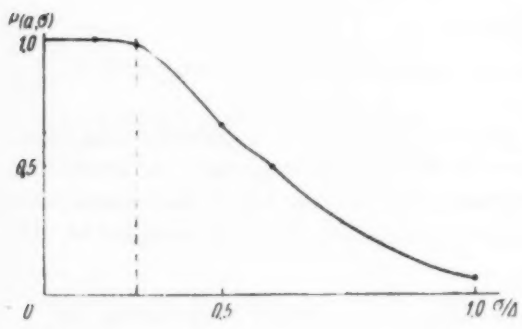

Fig. 2

1. All n_1 lie simultaneously within intervals $(-\Delta, \Delta)$ and $(-\Delta_0, \Delta_0)$; or 2) all n_1 lie within the interval $(-\Delta, \Delta)$, but not all of them are in the interval $(-\Delta_0, \Delta_0)$.

Similar to the foregoing, the probability that all n_2 observations will fall within the interval $(-\Delta, \Delta)$ is equal to P^{n_2}.

Then, according to the equation of the total probability, we obtain the following relation for the probability P_N of accepting the hypothesis:

$$P_N = P_0^{n_1} + (P^{n_1} - P_0^{n_1})\, P^{n_2}. \tag{4}$$

At the beginning, we assumed that the errors in instrument indications were normally distributed; if we assume that the distribution parameters are a and σ, then, using (4), we obtain

$$P_0 = \frac{1}{\sqrt{2\pi}} \int_{-\frac{\Delta_0 - a}{\sigma}}^{\frac{\Delta_0 + a}{\sigma}} e^{-\frac{t^2}{2}}\, dt = \Phi\left(\frac{\Delta_0 - a}{\sigma}\right) + \Phi\left(\frac{\Delta_0 + a}{\sigma}\right), \tag{5}$$

$$P = \frac{1}{\sqrt{2\pi}} \int_{-\frac{\Delta - a}{\sigma}}^{\frac{\Delta + a}{\sigma}} e^{-\frac{t^2}{2}}\, dt = \Phi\left(\frac{\Delta - a}{\sigma}\right) + \Phi\left(\frac{\Delta + a}{\sigma}\right) \tag{6}$$

and finally:

$$P_N = P(a, \sigma) = \left[\Phi\left(\frac{\Delta_0 - a}{\sigma}\right) + \Phi\left(\frac{\Delta_0 + a}{\sigma}\right)\right]^{n_1} + \left\{\left[\Phi\left(\frac{\Delta - a}{\sigma}\right) + \Phi\left(\frac{\Delta + a}{\sigma}\right)\right]^{n_1} - \left[\Phi\left(\frac{\Delta_0 - a}{\sigma}\right) + \Phi\left(\frac{\Delta_0 + a}{\sigma}\right)\right]^{n_1}\right\} \left[\Phi\left(\frac{\Delta - a}{\sigma}\right) + \Phi\left(\frac{\Delta + a}{\sigma}\right)\right]^{n_2}, \tag{7}$$

where Φ is Laplace's function.

It is obvious from (7) that the probability P_N that the hypothesis N will be accepted (or, in other words, that the instrument will be accepted as being in good condition according to the results of the above-indicated verification), depends not only on σ and Δ, by which, as is obvious from (1) and (3), the condition of the specimen is basically determined, but also on the numbers n_1 and n_2 of observations and on the half-length Δ_0 of the narrowed auxilliary interval. Therefore, generally, the probability P_N will not be equal to 1 when the instrument is in good condition and it will not be equal to zero if it is not so. This means that applying the given checking method, we shall, with a certain probability P_I, reject instruments in good condition, or, in other words, commit an error of the first kind, and with another probability P_{II}, we shall accept instruments not satisfying the technical requirements, or commit an error of the second kind.

For a given value of $\frac{\sigma}{\Delta}$, P_I and P_{II} will be, respectively, the average proportion of rejected good instruments, and the average proportion of passed bad instruments, out of the whole number of instruments which were tested.

For instance, assuming $n_1 = 3$, $n_2 = 10$, and $\Delta_0 = \frac{\Delta}{2}$, we obtain for $a = 0$ the following values for the probability P_N for various values of the ratio $\frac{\sigma}{\Delta}$ (see table).

The operative characteristic (i.e., the curve P_N vs. $\frac{\sigma}{\Delta}$) for the given checking method plotted according to the data from the table, is shown in Fig. 2 by a full line. The dotted line represents the "ideal" operative characteristic, corresponding to the case $n_1+n_2=\infty$. It is obvious from Fig. 2 that the operative characteristic of the given checking method is far from the ideal characteristic.

$\frac{\sigma}{\Delta}$	$\frac{\Delta}{\sigma}$	$P_N \cdot 100$ %	$(1-P_N) \cdot 100$ %
0.25	4	99.96	0.04
0.33	3	98.27	1.73
0.5	2	66.37	33.63
0.6	1.67	49.75	50.25
1.0	1.0	6.20	93.80

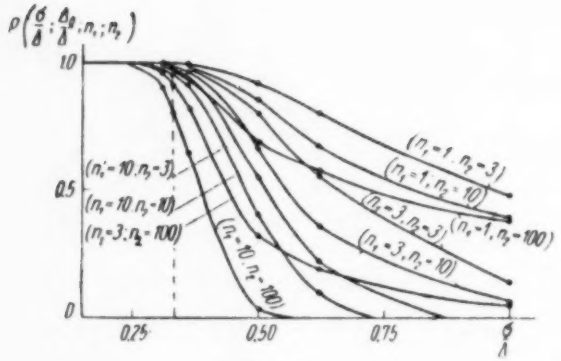

Fig. 3

Taking into account (1), we can write (3) in the form

$$\frac{\sigma}{\Delta} \leq \frac{1}{3},$$

i.e., the verified instrument must be considered as suitable if the ratio between the mean square of the deviation of the instrument indication errors and the maximum allowable error does not exceed $\frac{1}{3}$.

Thus, for values of $\frac{\sigma}{\Delta}$ smaller than $\frac{1}{3}$, the probability P_N is the probability of accepting good instruments and its complement $1 - P_n = P_I$ to unity is the probability of rejecting a good instrument. For values of $\frac{\sigma}{\Delta}$ greater than $\frac{1}{3}$, the probability $P_N = P_{II}$ represents the probability of accepting bad instruments. Only for the "ideal" operative characteristic we have $P_I = P_{II} = 0$.

It can be seen from the table that for the given method of instrument checking, the probability P_I of rejecting a good instrument (committing an error of the first kind) is rather small; it is equal to 1.7% for $\Delta = 3\sigma$. However, the probability P_{II} of accepting a bad instrument (i.e., committing an error of the second kind) is exceedingly great: for instance, it is equal to 49.8 % for $\Delta = 1.67\ \sigma$ which is, in other words, the case where the actual maximum error of the specimen exceeds almost twice the maximum error established by standards.

The operative characteristic of the considered method as applied to one point on the scale, shows that if a large batch of instruments with a maximum error at one point equal to, for instance, $[\Delta_{lim}] = 3\ \mu$ according to technical requirements, but actually having a maximum error equal to $\Delta_{lim} = 5.4\ \mu$, passes the test according to this method, then approximately one-half of the instruments will be accepted as suitable for application when, in fact, the use of such instruments could not be allowed.

However, attention should be drawn to a certain relativity of the quoted numerical values. At the beginning, we assumed that the checking of instrument errors is done only at one point of the scale. In fact, the verification is performed for several points.

Due to the connection which apparently exists between errors at these points, the evaluation of methods, when taking into account all points, must improve considerably. Having at our disposal the characteristics of the relation between errors at separate points and using approaches similar to the one described above, it is possible to plot the operative characteristic for the method of instrument checking for a given number of points on the scale.

Under these conditions, given the maximum values of errors of the first and second kinds, it is possible to find the number of points on the scale which have to be checked.

It can be easily seen that in the particular case, when the checking method comprises only one series of measurements for the calculation of the acceptance probability of hypothesis N, Eq. (7) assumes a similar form:

$$P_N = P^n = \left[\Phi\left(\frac{\Delta - a}{\sigma}\right) + \Phi\left(\frac{\Delta + a}{\sigma}\right) \right]^n \qquad (8)$$

From a consideration of operative characteristics of methods, it is possible to discern to what extent they safeguard the user from the application of low-quality instruments.

In connection with this, the problem arises of finding ways of increasing the reliability of methods. Here, we do not intend to give a definite answer to this question, as such an answer can be obtained only on the basis of corresponding rather extensive investigations. We shall only try to outline the objectives of further investigations on the basis of experience gained from the considered case. So, for instance, in the checking method for lever-mechanical instruments, without a consideration of the number of points on the scale, there are the following three parameters allowing various combinations: Δ_0 is the magnitude of the narrowed interval, n_1 is the number of observations in the first series, and n_2 is the number of observations in the second series.

Thus, the probability that hypothesis N will be accepted can be denoted by $P_N\left(\frac{\sigma}{\Delta}, \frac{\Delta_0}{\Delta}, n_1, n_2\right) = P_N\left(\frac{\sigma}{\Delta}\right)$, where $\frac{\Delta_0}{\Delta}$, n_1, and n_2 are parameters, and $\frac{\sigma}{\Delta}$, the argument.

It is of interest to perform a more detailed analysis of operative curves for checking methods with the aim of selecting such combinations of checking-method parameters for which we would obtain the highest reliability of evaluation as set against a reasonable amount of work involved in verification.

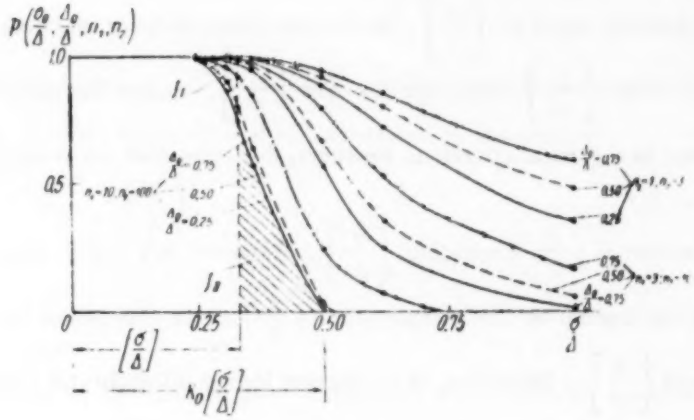

Fig. 4

Figures 3 and 4 show the operative curves for the hypothesis N for the following values of the parameter $\frac{\Delta_0}{\Delta}$: 0.25, 0.50, and 0.75, and for the following nine combinations of parameters n_1 and n_2:

1) $n_1=1$ $n_2=3$	4) $n_1=3$ $n_2=3$	7) $n_1=10$ $n_2=3$
2) $n_1=1$ $n_2=10$	5) $n_1=3$ $n_2=10$	8) $n_1=10$ $n_2=10$
3) $n_1=1$ $n_2=100$	6) $n_1=3$ $n_2=100$	9) $n_1=10$ $n_2=100$ *

Let us remark that the behavior of curves to the right of point $\frac{\sigma}{\Delta}=1$, corresponding to the value $\Delta_{lim} = 3\,[\Delta lim]$, is of no practical significance, as for high values of Δ_{lim} the unsuitability of the instrument is, in general, simply revealed.

It is obvious from the graphs that with a change of the checking method parameters, the operative curve of the method changes considerably. Combining the values of the checking-method parameters, we can select an optimum variant from the viewpoint of minimizing the probabilities of errors of the first and second kinds.

* In practice, usually, n_1, $n_2 \leq 10$. The value $n_2 = 100$ was taken for the sake of clarity. For large n_1 or n_2, it is more convenient to evaluate σ according to $\bar{s}$ which is the empirical, more precisely defined mean square deviation (see [1]). The case where $n_1 \geq n_2$ was not considered because it is usually not encountered in practice.

Thus, the indicated probabilities can be used even by themselves as objective criteria for the evaluation of the quality of checking methods. Moreover, on the basis of an extensive investigation of checking methods and the results of their application in practice, it is possible apparently to formulate standard requirements for the methods with respect to their safeguarding the reliability of verifying the metrological and operational characteristics encompassed by them.

However, it is sometimes inconvenient to judge a checking method with respect to two criteria simultaneously. Such a situation can arise, for instance, in the comparison of two methods, where one of them provides a lesser probability for an error of the first kind than the other, but where the probability of committing an error of the second kind is greater, and the problem is reduced to the question which of the two is to be preferred.

It is understandable that such a problem should be solved on the basis of an evaluation of the actual importance of errors of the first and second kinds in each concrete case. The unification of probabilities of these errors will be to a certain extent conditional. Nevertheless, for the sake of simplicity and clarity, we would be justified in an attempt to find a generalized criterion. Consider the operative curves plotted in Fig. 4. Let us denote by $\left[\frac{\sigma}{\Delta}\right]$ the value of the ratio $\frac{\sigma}{\Delta}$ allowed by technical requirements imposed on the instruments. Consider the areas under the $P\left(\frac{\sigma}{\Delta}\right)$ curves. For the "ideal" characteristic, it is determined by the product $1 \times \left[\frac{\sigma}{\Delta}\right]$, i.e., it is numerically equal to $\left[\frac{\sigma}{\Delta}\right]$. For actual characteristics, the area F_1 under the curve $P\left(\frac{\sigma}{\Delta}\right)$ in the interval from 0 to $\left[\frac{\sigma}{\Delta}\right]$, is always less than $\left[\frac{\sigma}{\Delta}\right]$. At the first glance, it seems that the ratio $\frac{F_1}{\left[\frac{\sigma}{\Delta}\right]}$ could be accepted as a general criterion. However, this ratio does not take into account the behavior of the $P\left(\frac{\sigma}{\Delta}\right)$ curve for values of $\frac{\sigma}{\Delta}$ exceeding $\left[\frac{\sigma}{\Delta}\right]$. However, this is very important, as the probability for an error of the second kind depends on how steeply the $P\left(\frac{\sigma}{\Delta}\right)$ curve approaches the abscissa at the portion lying to the right of the point $\left[\frac{\sigma}{\Delta}\right]$. Therefore, as a criterion for the reliability of a checking method, for instance, the following quantity can be accepted:

$$N = \frac{F_0}{\left[\frac{\sigma}{\Delta}\right]}, \tag{9}$$

where

$$F_0 = \left[\frac{\sigma}{\Delta}\right] - f_I - f_{II};$$

f_I is the area enclosed between the ideal and the actual operative curves in the interval from 0 to $\left[\frac{\sigma}{\Delta}\right]$ and,

f_{II} is the area under the actual operative curve in the interval lying between limits from $\left[\frac{\sigma}{\Delta}\right]$ to $K_0\left[\frac{\sigma}{\Delta}\right]$ (here, K_0 is a constant factor depending on the actual maximum value for σ for the considered characteristic feature of the instruments).

If the actual operative curve coincides with the ideal curve, then, as can be seen from Fig. 4, $f_I = f_{II} = 0$ and therefore, $F_0 = \left[\frac{\sigma}{\Delta}\right]$ and N = 1.

In all other cases, the criterion N is less than one. The closer its value to one, the greater, obviously, the reliability of the checking method in the sense of securing by it the minimization of the probability of errors of the first and second kinds.

The calculation of the reliability criterion of the checking method can be performed analytically or graphically. In the latter case, it is convenient to plot the operative curves on ordinary millimeter graph paper.

A more rigorous reliability criterion for checking methods can be obtained if we have at our disposal the information on the distribution of the $\frac{\sigma}{\Delta}$ ratio for the given type and size of instruments.

In this case, the probability of encountering a good instrument in checking will be equal to

$$F\left\{\left[\frac{\sigma}{\Delta}\right]\right\} = \int_0^{\left[\frac{\sigma}{\Delta}\right]} p\left(\frac{\sigma}{\Delta}\right) d\left(\frac{\sigma}{\Delta}\right). \tag{10}$$

where $p\left(\frac{\sigma}{\Delta}\right)$ is the distribution density of the ratio $\frac{\sigma}{\Delta}$ for the given type and size of instruments; and the portion of good instruments, thereby accepted will be determined by the integral

$$P' = \int_0^{\left[\frac{\sigma}{\Delta}\right]} P_N\left(\frac{\sigma}{\Delta}, \frac{\Delta_0}{\Delta}, n_1, n_2\right) P\left(\frac{\sigma}{\Delta}\right) d\left(\frac{\sigma}{\Delta}\right). \tag{11}$$

Consequently, the portion of encountered good instruments which were not accepted will be equal to

$$P_I' = F\left\{\left[\frac{\sigma}{\Delta}\right]\right\} - P'. \tag{12}$$

The portion of bad instruments encountered in checking which were accepted will be equal to

$$P_{II}' = \int_{\left[\frac{\sigma}{\Delta}\right]}^{\infty} P_N\left(\frac{\sigma}{\Delta}, \frac{\Delta_0}{\Delta}, n_1, n_2\right) P\left(\frac{\sigma}{\Delta}\right) d\left(\frac{\sigma}{\Delta}\right). \tag{13}$$

Then, as a reliability criterion for the checking method, the following quantity can be accepted:*

$$N_1 = 1 - P_I' - P_{II}'. \tag{14}$$

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* Criterion N_1, based on the distribution of $\frac{\sigma}{\Delta}$, was proposed by E. F. Dolinski in a somewhat different form.

which represents the portion of instruments accepted without error on the basis of the chosen variant of the checking method, which is, however, not so easy to calculate.

SUMMARY

On the basis of the state of contemporary statistical mathematics, it is possible to formulate and scientifically substantiate objective criteria for the reliability of methods of checking measuring instruments.

LITERATURE CITED

[1] I. V. Dunin-Barkovskii and A. N. Karpasheva, The Probability Theory and Statistical Mathematics in Engineering (General Part) (Gostekhizdat, Moscow-Leningrad, 1955).

FIRST INTERNATIONAL CONGRESS ON AUTOMATIC CONTROL

The National Committee of the Soviet Union for Automatic Control was formed at the USSR Academy of Sciences.

On the recommendation of the International Federation for Automatic Control (IFAC), the National Committee of the Soviet Union for Automatic Control will organize and hold the first international congress in Moscow from June 25 to July 5, 1960.

The congress will hear and discuss reports comprising theoretical and practical problems in the domain of the theory of automatic regulation and control, technical means of automation and remote control (including computers), and industrial application of automatic regulation and control (including the application of computers) in various branches of technology.

Scientifico-Technical committees were formed at the National Committee of the Soviet Union, which were entrusted with the preparation and selection of scientific reports to the congress on our part on the following subjects:

1) theory of automatic regulation and control;

2) technical means for automation and remote control;

3) automatized electric drive and application of electrical machines;

4) automatization of continuous industrial processes in the metallurgical, chemical, energetic, and other branches of industry;

5) automatization of industrial processes in machine building;

6) terminology.

Reports to the congress will be submitted through the National Committee of the Soviet Union for Automatic Control under the heading: "To the Congress on Automation." The address of the National Committee is: Moscow, I-53, Kalanchevskaya St., 15-a.

All those wishing to submit reports must send to the National Committee short summaries (not over three pages of typewritten text without drawings) in four copies, with indicated business and home addresses and telephone number, before February 15, 1959.

The full texts of the reports in four copies not exceeding twelve typewritten pages (double spaced), containing not more than five drawings with figure captions, must be submitted not later than May 15, 1959.

All the accepted reports will be published in due time in Russian and in English.

The National Committee asks the authors to submit the summaries and the reports not only in Russian but also in English.

The National Committee will advise all authors about the decision of the executive committee of the IFAC with respect to the inclusion of reports in the program of the congress.

DETERMINATION OF ERRORS IN MECHANISMS WITH LOWER PAIRS

V. A. Shishkov

In the calculation of errors in a real mechanism the permissible variations in the dimensions of its links and the deviations in the position of the centers of pins or slots on the column are usually given. The errors in position of other links for the given position of the driving link have to be found.

The graphical method of determining small displacements suggested by Academician N. G. Bruevich, in which modified mechanisms are usually constructed for each original error can be extended in two directions. Firstly, a unified diagram of small displacements of mechanism links due to production errors can be constructed without resorting to the theory of modified mechanisms, by using the diagram of the given mechanism. Secondly, a considerable unification of terms and methods already accepted and used in the construction of velocity and acceleration polygons is possible. All this simplifies construction and makes possible the representation in a compact form of all the errors in a complex mechanism.

The construction of the diagram of small displacements has much in common with the construction of the velocity diagram, but it also has some differences; it has some elements which link it with the acceleration polygon. The differences are as follows:

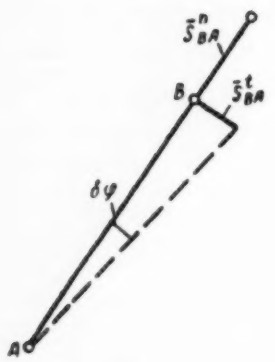


Fig. 1

The motion of any point is due to the defective displacement of all the other points from positions which they would have occupied in a perfect mechanism, rather than to the motion of the driving link.

The original displacements of points are quantities which are independent of one another. These are elongations (or shortenings) of links and displacements of the centers of pins and slots. During the construction of the diagram they are magnified by the mechanism links.

Let us assume that errors in lengths and play are so small that the direction of the links of the real mechanism coincides with the theoretical direction, except for an error permissible in drawing the displacement, velocity, or acceleration polygons of lines parallel or perpendicular to these links.

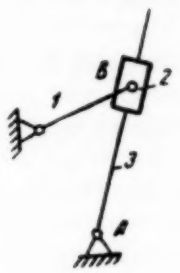
The point B of any link AB (Fig. 1) can have (compared with the theoretical displacement) undesired displacements in two directions: motion in the AB direction due to the change in the length of the link with respect to its ideal length, and a motion perpendicular to AB due to the error $\delta\varphi$ in the angular position of the link. Let us call these displacements the normal displacements $\bar{s}^n_{BA}$ and the tangential displacement $\bar{s}^t_{BA}$, respectively, thus referring to the possible trajectory of the point B with respect to its motion about the point A. Here the additional analogy with the conventional method of constructing the acceleration diagram is that the normal displacement is always known with regard both to its size and its direction (this is the given deviation in the length of the link), while the direction of the tangential displacement is usually known. The only point where the analogy does not apply is that the normal displacement can occur in the direction from the point B to the point A and vice versa, according to whether the link of the real mechanism has been shortened or lengthened compared with the link of the theoretical mechanism.

Figure 2 gives vector equations for a number of typical cases; they can be used for determining the displacement of one point from the displacement of the other. These equations can be readily understood by anyone who has experience in the construction of velocity and acceleration polygons. In the equations, the vectors underlined by a double line are known by size and direction, while of the vectors underlined by a single line only the direction is known.

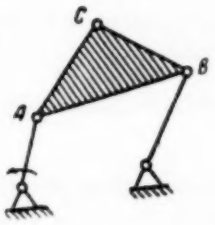
$\bar{S}_B = \bar{\bar{S}}_A + \bar{\bar{S}}^n_{BA} + \bar{S}^t_{BA}$

$\bar{S}_{B_1} = \bar{\bar{S}}_{B_0} + \bar{S}_{B_1B_0}$,
where $\bar{S}_{B_0}$ — is the translation of the slot.

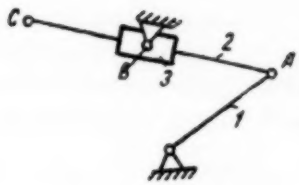
$\bar{S}_{B_2} = \bar{\bar{S}}_{B_1} + \bar{S}_{B_2B_1} = \bar{\bar{S}}_A + \bar{S}^t_{B_2A}$
(In the moving pair the distance AB_2 can be considered to be equal to the theoretical distance and $\bar{S}^n_{B_2A}=0$).



$\bar{S}_C = \bar{\bar{S}}_A + \bar{\bar{S}}^n_{CA} + \bar{S}^t_{CA} = \bar{\bar{S}}_B + \bar{\bar{S}}^n_{CB} + \bar{S}^t_{CB}$



$\bar{S}_{B_2} = \bar{\bar{S}}_{B_1} + \bar{S}_{B_2B_1} = \bar{\bar{S}}_A + \bar{S}^t_{B_2A}$ (again $\bar{S}^n_{B_2A}=0$)
$\bar{S}_C = \bar{\bar{S}}_{B_2} + \bar{\bar{S}}^n_{CB_2} + \bar{S}^t_{CB}$.



$\bar{S}_C = \bar{\bar{S}}_B + \bar{\bar{S}}^n_{CB} + \bar{S}^t_{CB}$

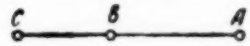


Fig. 2

In Fig. 2 as well as in other diagrams and equations the displacement of each point with respect to its theoretical position is considered as a sum of the translation of the entire link together with a certain point whose displacement is known, and of the relative motion with respect to this point. The index BA denotes the displacement of the point B with respect to A, etc.

In the two last equations of Fig. 2, the tangential displacements are determined from the proportionality to the distances from the center of rotation in turning the link through a small angle, which is shown in greater detail in the examples given below.

In constructing the diagram of small displacement we shall assume that the element by means of which the last driven link is connected to the column coincides with its own theoretical position. A pin, slot, etc., can act as such an element. The displacements of the axes of other pins or directions of slots are considered to be known with respect to the coordinate system connected with this "last" element.

In the following we give examples of the determination of errors in the positions of mechanism links. The pole of the polygon of small displacements is denoted by p_s.

The construction of the polygon of small displacements for a crank-slider mechanism is shown in Fig. 3. We assume that the direction DE of the crosshead slideway coincides with the theoretical direction. The center of rotation A of the crank has a displacement indicated on the diagram through the vector $\bar{S}_A$ drawn from the pole. The displacement of the point B from its theoretical position is represented as consisting of two components: a linear displacement of the link AB together with the point A, and the displacements of the point B with respect to the point A, due to changes in the length of the crank AB. The displacement $\bar{S}^n_{BA}$ directed parallel to the line AB must be added to the displacement $\bar{S}_A$ on the polygon of small displacements. There is no tangential displacement $\bar{S}^t_{BA}$ if the angle of the original link is given, and therefore contains no error. The straight line $p_s b$ (dotted) indicates the absolute displacement of the point B of the mechanism.

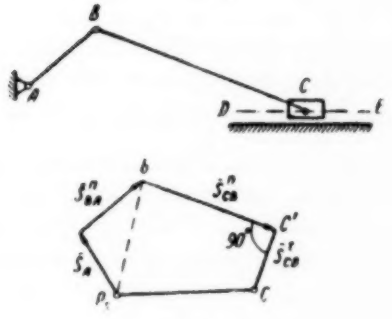


Fig. 3

In determining the displacement of the point C we now consider the translation of the link BC, together with the point B, as the transfer motion. In this motion the point C moves from its theoretical position onto the line $p_s b$, which is already on the polygon. It is now only necessary to add the relative displacement consisting of two components: normal and tangential. The normal displacement $\overline{s}^n_{CB}$ is caused by a change in the length of the connecting rod BC. In the example, the connecting rod is considered to be longer than its theoretical size, if it were shorter the length should be taken on the same straight line but in the opposite direction.

However, one component $\overline{s}^n_{CB}$ is inadequate for ascertaining the actual displacement of the point, since it has taken the position c' which is not connected with the mechanism. As usual, for easier understanding, the displacement polygon can be on the mechanism diagram with the pole p_s over the point C, and the scale suitably reduced. Then, it becomes obvious that the point c' lies higher than DE by the amount by which it is higher than $p_s c$ on the small displacements polygon. In order to make this point coincide with the line DE the connecting rod BC must be rotated further; as a result the point C undergoes a small displacement perpendicular to BC. On the polygon of small displacements we draw the corresponding line $\overline{s}^t_{CB}$ up to the horizontal intersection. This horizontal represents in the polygon the direction of the possible absolute displacement of the point C. The distance $p_s c$ thus obtained is the error in the position of the crosshead C.

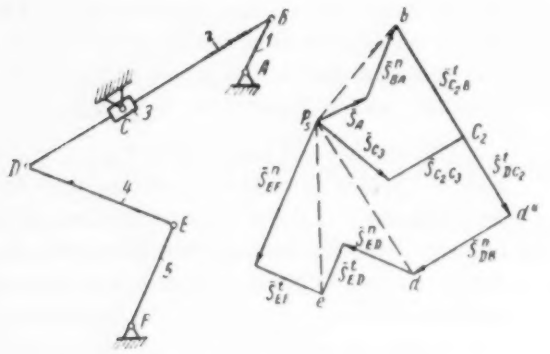


Fig. 4

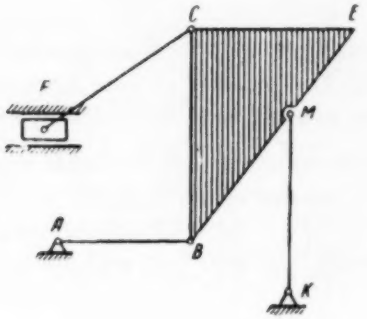
This clear method of transferring the displacement polygon to the point being considered can be used for any point of the mechanism.

The method has been described in considerable detail in order to show how small displacements can be plotted graphically. On the diagram of the mechanism small displacements of points are hardly visible when drawn on the same scale as the lengths of the mechanism links, but they become clearly visible when transferred onto the large-scale polygon of small displacements. Like additional components to the displacements of other points already obtained, they are drawn either as a line on the link (when a change in its length or a displacement in a straight-moving pair must be expressed) or they are drawn perpendicular to the line (when the displacement during the relative rotation of the link up to the position limited by the connections, etc., must be expressed).

After this thorough introduction the following more complicated examples require no detailed explanation. Figure 4 gives the mechanism with the corresponding diagram of small displacements. The point F is considered to occupy the theoretical position. The displacements of points A and C are given by vectors, the changes of lengths $\overline{s}^n_{BA}$, $\overline{s}^n_{DB}$, $\overline{s}^n_{ED}$, and $\overline{s}^n_{EF}$ of the corresponding links are known. In all polygons the given displacements and the displacements to be calculated are indicated by vectors with arrowheads. If only the directions of displacements are known no arrowheads are used. For example, points C_2 and $\underline{e}$ are at the points of intersection of straight lines of the given direction. The tangential displacements of the point E with respect to F, i.e., $\overline{s}^t_{EF}$, is being sought. By dividing it through the length EF we find the error in the angle of rotation of the driven link 5. The absolute displacements of the points B, D, and E are expressed by orientated lines $p_s b$, $p_s d$, and $p_s e$ (represented by dotted lines). The polygon also makes possible the determination of the relative displacement $\overline{s}_{C_2C_3}$ in the straight-moving pair, i.e., of the displacement of the link DB in the guide sleeve C.

In the example considered, the distance BC_2 is assumed to be equal to the theoretical distance; from this assumption the point C_2 of the polygon was found. It is possible first to determine on the polygon, by the usual method of proportional division of lines, the theoretical position $\underline{d}$ of the point D, and add to it the change $\overline{s}^n_{DB}$ in the length of the link 2 which is completely in its elevation C_2D. The correctness of the construction method is supported by the fact that the tangential components $\overline{s}^t_{C_2B}$ and $\overline{s}^t_{DC_2}$ are proportional to arms CB and CD. The point $\underline{e}$ on the displacements diagram is found on the intersection of $\overline{s}^t_{ED}$ and $\overline{s}^t_{EF}$.

Figure 5 gives the schematic diagram and the polygon of small displacements of another mechanism. The displacements of points A and K with respect to the slot F, the position of which is assumed to coincide with the theoretical position, are given. The changes in the lengths of all straight lines on the links of mechanisms, including the separate straight lines MB and EM, are also given. The quantity being sought is $p_s f$, the error in the position of the slide F.



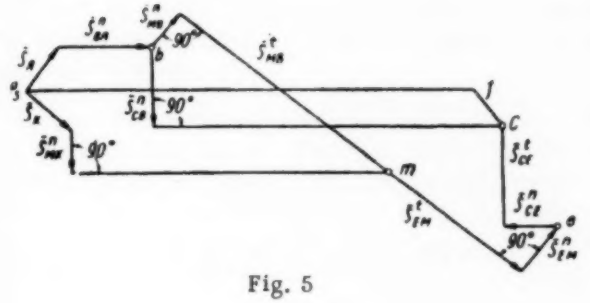


Fig. 5

We use the equation

$$\bar{S}_E = \bar{S}_M + \bar{S}^n_{EM} + \bar{S}^t_{EM},$$

for determining the displacements of the point E from the displacements of points B and M already found.

In this equation $\bar{S}^n_{EM}$ is the given elongation of the straight line EM. In addition, if the angular error of the link BE is small we have the proportion

$$\frac{S^t_{EM}}{S^t_{MB}} = \frac{EM}{MB},$$

We use it in the construction of the component $\bar{S}^t_{EM}$ in relation to $\bar{S}^t_{MB}$, i.e., it is in relation to the tangential components that the corresponding length is measured by the method of proportional division, which is usually applied in the construction of polygons. Thereupon, we add the second component $\bar{S}^n_{EM}$ and obtain the point e.

The displacement of the point C is found from points B and E which are already known, and then the displacement of the point F is found.

The straight lines $p_s b$, $p_s c$, $p_s e$, and $p_s m$ which are omitted from the drawing in order to avoid its overcrowding provide the absolute displacements of points B, C, E, and M. For determining the angular errors of links, the corresponding tangential relative displacements of points must be divided by the lengths of the links. For example, the error in the rotation of the straight line BM is expressed by the relation $\delta\varphi = \bar{S}^t_{MB}/MB$ radians.

SUMMARY

The method developed by the author makes possible the construction of a single polygon of small displacements without drawing the transformed mechanisms. The polygon of small displacements provides the complete solution of the problem of determining the effect of all links upon the position error of the driven link (and also upon the position error of any of the links of the mechanism).

Considering the displacement of the centers of curvature, and the changes in the radii of curvature of the profile, it is possible to extend the suggested method to cover mechanisms containing higher pairs.

PHOTOELECTRIC RECORDING OF INTERFERENCE FRINGES

Iu. P. Efremov

Up to 1000 mm gage blocks are measured on a large VNIIM horizontal interferometer by comparing their lengths with the length of a 100 mm Fabry and Perot master gage [1]. The accuracy of these instruments depends mainly on how precisely the length of the master gage is known at the moment when the comparison is made.

The length of these master gages can be measured most accurately in wavelengths of visible light by the absolute interference method, which in essence is reduced to the determination of the fractional part ϵ of the order of interference in the center of rings with equal slope. In order to find ϵ the interference rings produced by the master gage are usually photographed, whereupon the diameters D_k of several rings are measured; the calculation produces, by means of the equation [2]:

$$\epsilon = \frac{\Sigma\sigma - S s}{S k - s \Sigma}, \tag{1}$$

where k is the number of diameters measured (usually 5-6);

$$\Sigma = D_1^2 + D_2^2 + \ldots + D_k^2;$$

$$\sigma = 1^2 + 2^2 + \ldots + (k-1)^2;$$

$$S = D_2^2 + 2D_3^2 + \ldots + (k-1)\, D_k^2;$$

$$s = 1 + 2 + \ldots + (k-1).$$

A certain instability of the tubular steel master gages calls for rapid and accurate checks of their length during the measurements on sets of gage blocks. The method involving the taking of photographs is too laborious for this purpose.

In 1954 Baird suggested a simpler technique for determining ϵ [3]. The master gage of Fabry and Perot, consisting of two mirrors twisted onto the gage block, is placed in a chamber in which the pressure can be regulated by means of a pump fitted with a dial indicator. After isolating by means of an aperture the central portion of the picture interference, its brightness, which changes with the pressure in the chamber, is observed visually. The whole numbers of the order of interference (half-wavelengths) N ($\epsilon = 0$ or $\epsilon = 1$) correspond to the maximum values of brightness. At pressure p equal to the atmospheric pressure the fractional part of ϵ is determined by means of the following expression:

$$\epsilon = \frac{p - p_1}{p_2 - p_1}, \tag{2}$$

where p_1 and p_2 are the pressures at which two subsequent brightness maxima were observed; $p_1 < p < p_2$.

This paper deals with the replacement of the visual observation method by photoelectric recording, which makes the measurement of the fractional part of the order of interference ϵ more objective and accurate.

The schematic diagram of the set-up is given in Fig. 1. Its optical part represents a modification of the monochromatic interferometer developed earlier at the All-Union Scientific Research Institute of Metrology (VNIIM) [4], and together with the electrical part is similar to the apparatus used for the recording of the fine and superfine structure of lines of the spectrum [5, 6, and 7].

From the lamp 1 with an isotope of cadmium Cd^{114} the light is passed by means of the condenser 2 through the slit 3 into the unit 4 which changes the light to monochromatic; its slit 5 lies in the focal plane of the collimator objective 6 whose focal length is F = 550 mm. The Fabry and Perot tubular steel master gage 7, which has mirrors on the optical contact, enables the air pressure to be varied to values above and below the atmospheric pressure, sufficient for measuring its optical length within several orders of interference. The height of the slit 5

is restricted in such a manner that the cathode of the electron multiplier 9 receives light only from a certain part Δ of the central interference ring. The aperture 8 restricts the amount of dissipated light falling onto the multiplier cathode.

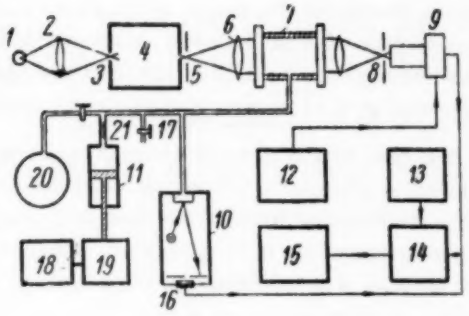


Fig. 1

The micromanometer 10 which is connected to the master gage 7 and pump 11 indicates the variations of pressure in the master gage. The supply to the photomultiplier 9 and amplifier 14 is from units 12 and 13.

An N-16 recording unit with a photo-compensating amplifier and an EP1-02 recording electron potentiometer with an amplifier based on the 6F5 tube were used as the recorder 16. In the first case the FÉSS photocell connected to the amplifier output was used as the pressure gage. The photocell is shielded by a screen with a narrow slit which is placed in such a manner that a short impulse is sent into the amplifier and the recording unit makes a mark at the moment when the light indicator of the microammeter passes through the position corresponding to the pressure p. In the second case the mark was produced by switching on the input of the EP1-02 recording unit at the required moment for a short time.

During the measurements the valve 17 was opened, and produced in the master gage pressure p equal to the atmospheric pressure. The light indicator of the microammeter was at that time set to zero. Then the valve 17 was closed and the electric motor 18 started; it drives the plunger of the pump 11 through the reduction gear 19; this reduces the pressure in the master gage to a level adequate for changing its optical length by 1.5 to 2 orders, i.e., the pressure was reduced to 10-12 mm Hg. Thereupon, the photorecording part of the set-up was switched on and the pressure in the standard gage gradually raised by reversing the direction of motion of the pump plunger.

A mark is made on the diagram either automatically or by pressing a button at the moment when the micromanometer indicator passes through zero. After recording 2-3 orders with the pressure mark p between two of them, the recording is repeated with the pressure changing in the reverse direction.

The rate at which the pressure is changed within the narrow range on either side of the atmospheric pressure can be made sufficiently uniform by suitably selecting the capacity of the additional cylinder 20 and the size of the capillary 21; for determining the fractional part ϵ, therefore, the following simplified equation can be used instead of Eq. (2):

$$\epsilon = \frac{l}{L}, \tag{3}$$

where

l is the distance on the diagram between the maximum corresponding to the pressure $p_1 < p$ and the mark, and

L is the distance between the maxima corresponding to pressures p_1 and p_2 when $p_1 < p < p_2$.

The recording is made with the pressure changing in both directions, in order to eliminate the systematic error due to the inertia of the moving parts of the recording device, and also the errors due to the possible differences between the indications of the micromanometer and the actual pressure in the master gage. The arithmetic mean of ϵ_1 and ϵ_2 values obtained in the forward and reverse directions of pressure measurement (Fig. 2) was adopted as the result.

The accuracy with which ϵ is determined depends on the precision with which the pressure marks p are applied and on the accuracy with which the position of maxima on the diagram is determined. With a suitably selected micromanometer light indicator the pressure mark can be applied with a time error of 0.1 second, which produces an error of 0.02 mm in the position of the mark on the diagram; this produces an error of 0.001 orders of interference in the determination of ϵ, because when the pressure changes at the rate of 4-5 mm Hg per minute

and the tape of the recording unit travels at 0.2 mm/sec, the distances between the adjacent maxima are 15-20 mm. The distances between the maxima and the mark are easily determined with an error of 0.05 mm, which produces an error of 0.005 orders of interference in the determination of ϵ.

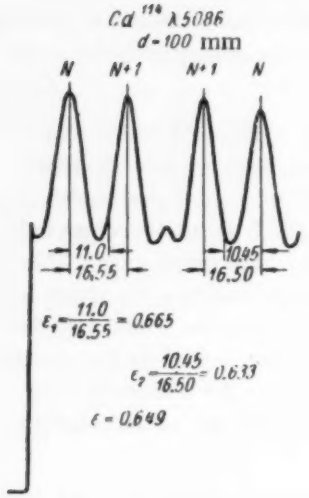


Fig. 2

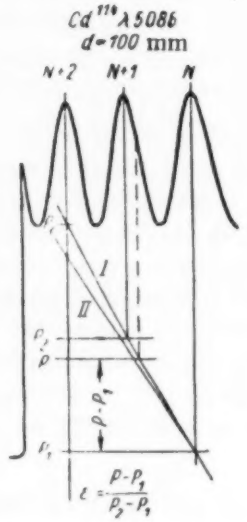


Fig. 3

In measuring class I gage blocks, it is sufficient to determine the length of the Fabry and Perot master gage with an accuracy of up to 0.003 μ, and, consequently, the fractional part ϵ of the order of interference with an accuracy of up to only 0.01.

In the case of a noticeable nonuniformity in the variation of pressure in the master gage the values of ϵ determined from (3) become incorrect. The following procedure is then adopted. After recording at least 3 interference maxima during the variation of pressure in one direction, a pressure curve (curve 1 in Fig. 3) is plotted on the diagram. The basic points for the construction of this curve are the positions of maxima, the distances between which on the pressure axis (the Y axis) must be equal. Knowing the position of the pressure mark p, it is easy to calculate from (2) the difference $p - p_1$ and the value of ϵ corresponding to the pressure p.

During the photoelectrical recording the maxima always appear shifted in the direction of the higher pressure, i.e., in the direction of the higher order of interference. Therefore, the value ϵ found from (3) or (2) is always smaller than the actual value by the amount $\delta\epsilon$. In 1949, attention was drawn to the existence of such displacement: the maximum intensity of light passing through the interference unit producing monochromatic light was obtained at interference orders slightly higher than one [4].

The theory of these phenomena was given later [8, 9, and 10]. It was established that in the case of a circular aperture which isolates a certain part Δ of the central interference ring, the correction $\delta\epsilon$ for the recording of symmetrical interference fringes is equal to exactly half of Δ ($\delta\epsilon = \frac{1}{2}\Delta$). In the case of a square orifice the correction $\delta\epsilon$ is equal to the correction for the circular aperture inscribed in the square.

For a circular aperture with a radius r the value of Δ is calculated from the equation

$$\Delta = \frac{ndr^2}{\lambda F^2}. \qquad (4)$$

For the set-up shown in Fig. 1 the value of Δ was determined from the dimensions of the square aperture 3 and the focal length F of the objective 6.

SUMMARY

The comparison of the results of measurements of Fabry and Perot master gages obtained by the photoelectric recording and by taking photographs of interference rings was carried out for a 100-mm-long master gage and for 47-, 80-, and 100-mm long quartz gages. In each case the result coincided with the difference remaining within measurement errors.

Advantages of the photoelectric recording method include: its objectivity, reliability, and the speed with which the result is obtained. In addition, the use of this method offers wide possibilities for using in the interference length-measurements of spectral lines from the part of the spectrum close to the infra-red region, which makes possible the extension of the range in which absolute measurements of gage blocks in wavelengths of light can be performed.

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INSPECTION OF THE COMMON NORMAL OF THE GENERATING LINES OF STRAIGHT BEVEL GEARS

P. M. Danilluk

The measurement of the length of the common normal is the simplest and most easily applied method of indirect inspection of the tooth thickness of spur gears. This method is also used in checking the thickness of the teeth of bevel gears on their faces. However, the need for the teeth faces to make contact with a flat surface of the measuring device reduces the accuracy of this method. We therefore suggest a new method of checking the common normal of the generating lines of straight bevel gears, as it has no shortcomings of the above type.

It is known that every cylinder can be represented as a cone with the base equal to the base of the cylinder and an infinitely distant apex. A similar relationship exists between spur and bevel gears, and this was used in the solution of the problem.

Let a spur gear have a module $\underline{m}$, the nominal teeth thickness on the pitch circle of half pitch, and two parallel planes P_1 and P_2 (Fig. 1) tangential to opposing cylindrical evolute surfaces of two teeth with symmetrical generating lines. The distance L between these planes is equal to the length of the common normal of gears, which can be calculated with the familiar equation.

In order to transform this spur gear into a bevel gear the apex of the spur gear must be brought from infinity to a point at the required distance from the pitch circle plane of the gear in question. During this process the cylindrical evolute surfaces and the planes P_1 and P_2, which intersect on the axes of the mating gears, must form an angle ω (Fig. 2). Now, for checking the common normal of the gear it is sufficient to measure the angle formed by the planes instead of measuring the linear length of the common normal.

Most modern machine tools for cutting straight bevel gears with reciprocating cutters operate on the generation (rounding) principle. As is known, bevel gears produced by this method have, in the spherical section, the so-called octoidal rather than the evolute profile. However, as was established in [1], although the octoidal profile actually lies outside the evolute contour, the deviations of the teeth of normal height are in effect quite

insignificant and can be ignored in practice. If, in addition, it is taken into account that in the case of evolute gearing all the calculations are much less complicated, and the final results very little different from the results of accurate calculations for the octoidal gearing, it is quite permissible to take the theory of evolute gearing as the basis for the calculation of the tooth thickness.

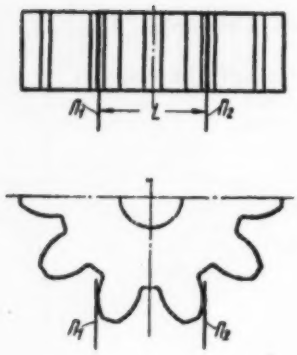

Fig. 1

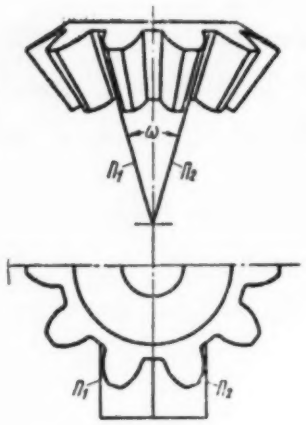

Fig. 2

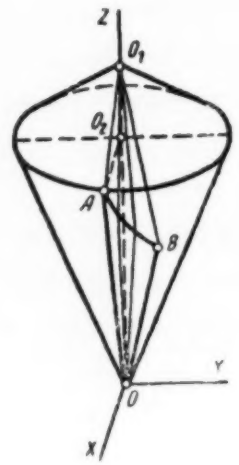

Fig. 3

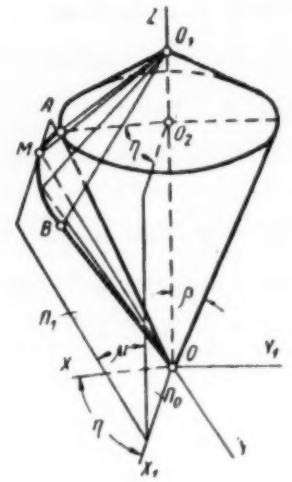

Fig. 4

In determining the angle ω we proceed as follows. Let us assume that the evolute conical surface ABO (Fig. 3) is given. We turn this surface through an angle η about the OZ axis in such a manner that the new vertical coordinate plane X_1OZ coincides with the common plane P_0 of the bevel gear (Fig. 4). Then the equations of the evolute conical surface assume the following form [2]:

$$X_1 = \frac{l}{\cos(\gamma_a - \gamma)} [\sin(\varphi - \eta)\sin(\varphi\sin\rho) + \\ + \cos(\varphi - \eta)\cos(\varphi\sin\rho)\sin\rho];$$

$$Y_1 = \frac{l}{\cos(\gamma_a - \gamma)} [\cos(\varphi - \eta)\sin(\varphi\sin\rho) - \\ - \sin(\varphi - \eta)\cos(\varphi\sin\rho)\sin\rho]; \qquad (1)$$

$$Z = \frac{l}{\cos(\gamma_a - \gamma)} \cos(\varphi\sin\rho)\cos\rho,$$

where: X_1, Y_1, and Z are the coordinates of the points of intersection of a turned evolute conical surface with the back cone;

l is the length of the generating line of the pitch cone;

γ_a is the angle formed by the generating line of the conical evolute surface and the gear axis;

γ is the pitch cone angle;

φ is the angle of the developed surface; and

ρ is the angle of the base cone.

Let us now place through the OX_1 axis the plane P_1 tangential to the evolute conical surface. This plane forms with the vertical coordinate of the X_1OZ plane, which according to the original assumption coincides with the common axial plane, an angle μ. Thus, the angle μ is equal to half of the angle being sought, which is formed by the measuring planes:

$$\omega = 2\mu. \qquad (2)$$

The angle μ can be found as follows. The plane P_1 which is tangential to the evolute conical surface ABO is simultaneously tangential to the line AB formed by the intersection of this surface with the back cone at a point M. Let us assume that the coordinates Y_M and Z_M of this point are known. Then

$$\mu = \operatorname{arctg}\frac{Y_M}{Z_M}. \tag{3}$$

The coordinates Y_M and Z_M can be found from the Eq. (1) if the angle of the development φ for the point M of the evolute conical surface has been previously found. In solving the last-mentioned problem let us bear in mind that at the point M the coordinate Y_M reaches its maximum. Then, according to the general rule, we obtain:

$$\varphi = \eta.$$

For this value of the angle η the coordinates Y_M and Z_M are:

$$\begin{aligned} Y_M &= \frac{l}{\cos(\gamma_a - \gamma)}\sin(\eta\sin\varrho), \\ Z_M &= \frac{l}{\cos(\gamma_a - \gamma)}\cos(\eta\sin\varrho)\cos\varrho. \end{aligned} \tag{4}$$

By substituting these values of coordinates into (3), we obtain:

$$\mu = \operatorname{arctg}\left[\frac{\operatorname{tg}(\eta\sin\varrho)}{\cos\varrho}\right]. \tag{5}$$

Then the angle between the measuring planes is:

$$\omega = 2\operatorname{arctg}\left[\frac{\operatorname{tg}(\eta\sin\varrho)}{\cos\varrho}\right]. \tag{6}$$

The substitution into this equation of the values of angles η and ρ produces, after the relevant transformations, the final expression for the angle between the measuring planes:

$$\omega = 2\operatorname{arctg}\left[\frac{\sqrt{Z_1^2 + Z_2^2}}{\sqrt{Z_1^2\sin^2\alpha + Z^2}} \cdot \operatorname{tg}\left\{\frac{\cos\alpha}{\sqrt{Z_1^2 + Z_2^2}}[180°(n - 0.5) + Z_1\Theta_d]\right\}\right], \tag{7}$$

where

Z_1 is the number of teeth of the given gear,

Z_2 is the number of teeth of the mating gear,

α is the pressure angle,

$\underline{n}$ is the number of teeth simultaneously in contact, and

Θ_d is the angle of evolute.

The number $\underline{n}$ of mating teeth and the angle Θ_d of evolute are determined from the graph in Fig. 3 and the Eq. (14), respectively, which are given in [2].

The Eq. (7) was obtained under the assumption that the nominal tooth thickness s_d on the arc of the gear pitch circle is equal to half the pitch. If the thickness of teeth in cutting the gear were modified with the object of forming a clearance, or as a result of correction, then (7) can be written as follows:

$$\omega = 2\operatorname{arctg}\left[\frac{\sqrt{Z_1^2+Z_2^2}}{\sqrt{Z_1^2\sin^2\alpha+Z_2^2}}\operatorname{tg}\left\{\frac{\cos\alpha}{\sqrt{Z_1^2+Z_2^2}}[180°(n+\delta s_t-0{,}5)+Z_1\theta_d]\right\}\right]. \tag{8}$$

where δs_t is the factor showing the deviation of the tooth thickness from the nominal value expressed in terms of pitch.

In using this equation, δs_t is taken with a positive sign if the tooth thickness exceeds the nominal value, and with a negative sign if the opposite is the case. Otherwise, the equation is used in the same way as shown above.

The factor showing the deviation of tooth thickness from the nominal value which was obtained by this equation has either a positive or a negative sign. In the first case the tooth is thicker than the nominal size and in the second case thinner.

The actual deviation of the tooth thickness from the nominal value measured on the pitch circle is:

$$\Delta s_d = m\pi\delta s_t. \tag{10}$$

In order to obtain the actual tooth thickness on the pitch circle arc the value of δs_t thus found must be substituted into the following equation:

$$s_d = m\pi\,(0{,}5+\delta s_t). \tag{11}$$

Production inspection in the engineering industry involves the inspection of finished components and inspection during the manufacturing process.

The measurement of the common normal of straight bevel gears on the generating lines can, in the case of finished components having a bore, be performed as follows * (Fig. 5). The bevel gear is placed on a special mandrel 1, the tail end of which must fit tightly into the bore of the gear. The sides of the body 2 are inclined at an angle equal to the maximum limiting value of ω_{max} and must intersect on the axis of the mating gear, while the mandrel axis must run on the common axial plane of the gears. Two plates 3 are placed on the side surfaces of the body; they must fit into two tooth spaces. During the inspection of the gear, the tooth thickness of which is the maximum permissible, the opposing conical surfaces of two teeth touch the plate at two symmetrical generating lines. If the tooth thickness is different from this size, a gap will be observed between the generating lines of the tooth faces and the corresponding planes of the plates during the inspection. If the teeth are thicker, the gap will be observed at the internal back cone, and if the teeth are thinner, the gap will be observed at the external cone.

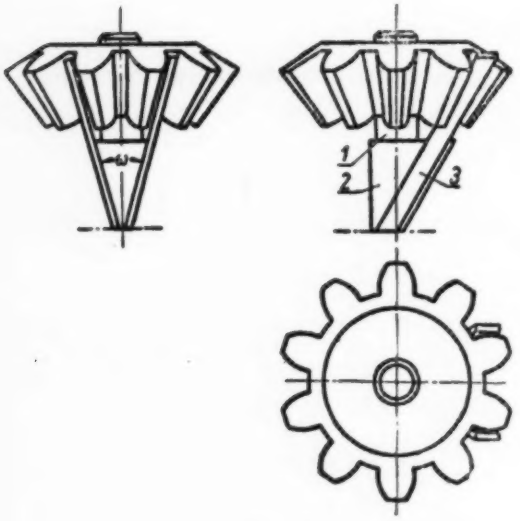

Fig. 5

The suggested inspection method can also be used in determining the actual thickness of the teeth of bevel gears from the data of actual measurements of the angle ω. For this purpose the Eq. (8) can be transformed as follows:

$$\delta s_t = \frac{1}{180°}\left\{\frac{\sqrt{Z_1^2+Z_2^2}}{\cos\alpha}\operatorname{arctg}\left[\frac{\sqrt{Z_1^2\sin^2\alpha+Z_2^2}}{\sqrt{Z_1^2+Z_2^2}}\operatorname{tg}\frac{\omega}{2}\right]-Z_1\theta_d\right\}-(n-0{,}5). \tag{9}$$

* Author's Certificate No. 108910 of Sept. 5, 1957.

If the planes of the plates touch the faces of the teeth close to the internal back cone, then the size of the gaps at the external back cone can be calculated in accordance with the thickness tolerance, from the equation

$$c_e = \frac{b}{2l\cos\alpha}\delta s, \tag{12}$$

where

b is the tooth width, and

δs is the tooth thickness tolerance measured on the constant chord.

If the ratio of tooth width to the length of the generating line of the pitch cone is denoted by k, then for a pressure angle $\alpha = 20°$ the maximum gap on one side at the external back cone is

$$c_e = 0.532\ k\delta s. \tag{13}$$

By the method described the inspection of the tooth thickness of bevel gears can be performed as shown in Fig. 5, without the use of the gear end face as a reference plane in cases when the design of the gearing provides for an axial adjustment. In this case the inspection results will not indicate the actual size of the clearances between gears, which can be determined only after the gear has been installed and adjusted. In order to reduce the side clearance it will be useful to apply, for the inspection of the gear, two mandrels whose plates must be set at different angles corresponding to the upper and lower limits of tooth thickness. The use of such mandrels is similar to the use of limit gages or gages for the inspection of angles.

In the case when the gear has no axial adjustment the inspection should involve the checking of the position of the gear end face in order to ensure the required side clearance between the teeth of the gears as well as the checking of teeth thickness. For this purpose, if the front end face of the gear is the reference plane, it is sufficient to provide on the mandrel corresponding shoulders which restrict the axial displacement of the gear in the direction of the pitch cone apex. During the inspection a gap can appear between the plates and the gear teeth or between the gear end face and the mandrel shoulder. The size of the gap between the plates and the gear teeth shows the thickness of the teeth. The maximum total gap at the external back cone is in this case:

$$c_{max} = \frac{\delta s}{\cos\alpha} \tag{14}$$

or, for a pressure angle $\alpha = 20°$,

$$c_{max} = 1{,}064\delta s. \tag{15}$$

The gap between the end faces of the mounting reference plane of the gear and the mandrel shoulder indicates only the deviation in the position of the mounting reference plane of the gear.

If the rear end face of the gear is the reference plane for mounting, then for the examination of its position it is sufficient to place the end face of the mandrel at a definite distance from the apex of the pitch cone or from the end of the mandrel. During the inspection the size of the gap between the plates and the teeth at the external back cone indicates the thickness of the teeth in the manner indicated previously, and the position of the mandrel end face in respect to the rear end face of the gear shows the position of the reference face for the mounting of the gear.

If the gear being inspected has no bore but is integral with the shaft, then the plates can be fixed on a vee-block, for which the shaft of the component is the reference element.

In laboratory measurements the actual thickness of teeth can be determined from (9) after measuring the angle between the symmetrical generating lines by means of a precision optical indexing head or a sine bar, by turning the gear about the axis of the mating gear and finding the direction of the generating lines by means of a dial gage.

Inspection during the manufacturing process includes the measurement of the teeth thickness and the inspection of the angle under which the generating cutters move; this measurement must be carried out without unloading the component. Here again it is advisable to use the suggested inspection method. For this purpose,

as was pointed out with respect to the gear integral with the shaft, the plates must be mounted on a vee-block. One of the surfaces of the mandrel or the machine can be used as the reference element for this vee-block.

The Eqs. (7) and (8) can be used in the calculation of the limiting values of the angle between the measuring planes. In this case, according to the limits of the tooth thickness, the position of the tolerance field, and the upper limit of the tooth thickness, either the Eqs. (7) and (8) or Eq. (8) twice must be used, respectively.

If the nominal size equal to half of the pitch measured on the pitch circle is one of the limiting dimensions of the tooth thickness, then the nominal value of the angle ω is calculated from the Eq. (7), whereupon, the maximum or minimum value of this angle is determined from (8).

If both limiting values of the tooth thickness differ from the nominal value, then the Eq. (8) should be used twice for the calculation of the limiting values of the angle ω, each time with a different factor of deviation of the tooth thickness from the nominal value.

The Eqs. (7) and (8) are also suitable for the calculation of angular tolerances of the tooth thickness, which are equal to the difference in limiting values of the angle $\Delta\omega$, respectively.

Module on the back cone, in mm	Tolerance for tooth thickness on constant chord according to GOST 1758-42 (in μ)			Tolerance for tooth thickness on common normal determined on gener. lines (in min)			Maximum total gap at the upper back cone (in μ)		
	class of accuracy			class of accuracy			class of accuracy		
	2	3	4	2	3	4	2	3	4
1	50	110	170	8.96	19.71	30.46	53	117	181
2	50	110	170	4.48	9.86	15.23	53	117	181
3	50	110	170	2.99	6.57	10.15	53	117	181
4	60	120	190	2.69	5.38	8.51	64	128	202
5	60	120	190	2.15	4.30	6.81	64	128	202
6	80	140	240	2.39	4.18	7.17	85	149	255
7	90	150	250	2.30	3.84	6.40	96	160	266
8	90	150	250	2.02	3.36	5.60	96	160	266
9	90	150	250	1.79	2.99	4.98	96	160	266
10	90	150	250	1.61	2.69	4.48	96	160	266

The table gives as an example, and also to demonstrate the sensitivity of the suggested method as compared with the usual method of inspection of the constant chord, the tooth thickness tolerances on the constant chord, the angular tolerances and the values of the total maximum gaps of a gear with the number of teeth $Z_1 = 20$, which were calculated for different modules and classes of accuracy.

The table shows that the angular tolerances for gears of the same module but a different class of accuracy are proportional to the tolerances for tooth thickness at the constant chord. However, as the module increases, the values of angular tolerances of each class of accuracy decrease. Conversely, the total maximum gap between the plates and the teeth at the external back cone is proportional to the thickness tolerances of the tooth on the constant chord for different classes of accuracy as well as for increasing modules.

SUMMARY

In the case of the use of limit mandrels the plates of which are set at different angles corresponding to the upper and lower deviations of the tooth thickness, the suggested methods are most suitable for measuring small-module gears.

If the inspection is carried out by measuring the gap at the external back cone, then the suggested method is most suitable for medium- and large-module gears.

In the case of laboratory inspection the suggested method is suitable for gears of any module and any class of accuracy.

During the manufacture of mandrels or vee-blocks, and also during the setting of the gear in the indexing head or sine bar, relatively high deviations from symmetry in the position of the generating lines of the evolute conical surfaces of the two gears being inspected with regard to their common axial plane are permissible. Since this method has relatively little sensitivity to errors due to the unsymmetrical mounting of the component for the inspection, the difference of angles between the generating lines of side surfaces during the unsymmetrical and symmetrical positioning of the common axial plane is a negligible quantity compared with the angle being measured.

LITERATURE CITED

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[2] P. M. Daniliuk, Measuring Techniques 6 (1955).

ELECTRIC CONTACT METHOD OF MEASURING DIMENSIONS OF LOW-RIGIDITY COMPONENTS

A. S. Zykov

In the following the electric contact method is described which was developed by the author for determining dimensions of elastic, electrically conductive components of low rigidity, which makes use of the resilient properties of workpieces. Figure 1 shows two such components (the dimensions being inspected are indicated by arrows).

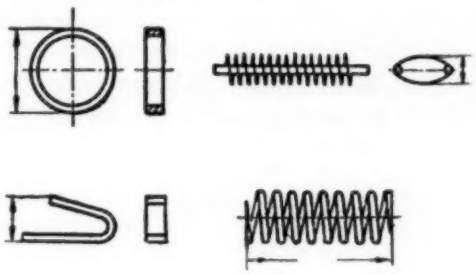


Fig. 1

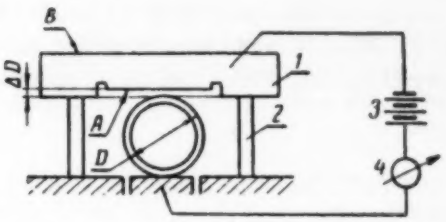


Fig. 2

Figure 2 shows the arrangement for measuring the external diameter D of a ring. The bar 1 which has two measuring faces, face A which corresponds to the upper limit of the dimension, and face B which corresponds to the lower limit, and supports 2 whose height is equal to the minimum size of the ring. The ring and the bar are connected into the circuit with the current supplied from source 3. When the bar is placed with the face A on the support, the "go" ring makes no contact with the bar, the circuit remains open and the recording unit 4, consisting of a signal lamp, indicates no current in the circuit. On the other hand, when the bar is placed with face B on the supports the correct ring makes a contact with the bar and the signal unit indicates the presence of a current in the circuit. For a reject these conditions are not met: in the first case, because the dimension being measured exceeds the upper limit of the tolerance field and in the second case because it remains below the limit.

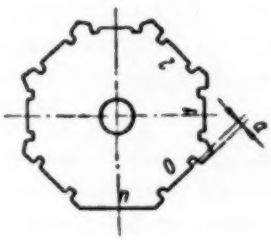


Fig. 3

Fig. 4

The low-power electrical impulses produced during the contact are amplified by an electron relay.

The maximum deformation of the accepted work produced during the measurement does not exceed the maximum tolerance of the dimension being checked, since the actual dimension of the component which is equal to the maximum permissible dimension, can be changed only up to the lower limit.

This method is suitable only for the measurement of workpieces whose maximum deformation produced during measurement is fully recoverable, i.e., the maximum stress in the strained component should not exceed the proportional limit.

In addition to the detection of rejects this method can be used in sorting components into dimension groups. In this case, the measuring element is polygonal (Fig. 3). If ΔD is the tolerance, then for n groups the number of sides of the polygon must be equal to $n+1$; the positions 0 and n of the polygonal disk can be "no go" positions, one being the upper limit and the other the lower limit.

The dimension a for each position of the disk is

$$a=\frac{\Delta D}{n}(n-k),$$

where $k = 0, 1, 2, \ldots, n$.

The experimental checking of the method was performed in the measuring and sorting of grids for receiver-amplifier tubes, according to the dimension A (Fig. 4); the diameter of the nickel coil wire was 0.045 mm, the cross wire 0.92 mm, and the pitch of the coil 0.13 mm. The tolerance for the dimension being inspected was ± 0.01 mm. The rigidity of each turn of the grid was negligibly small (only $6 \cdot 10^{-6}$ kg/μ).

The following conclusions can be drawn from the results of the investigations: the measurement errors due to the method did not exceed 0.05 μ at a test voltage of 6-24 v and with the contact area degreased; the shape and dimensions of the component before and after the measurement remained unchanged; no traces were left at the point of contact between the component and the current-carrying parts; the contact pressure depends only on the rigidity of the component and the direction of measurement, and on its deformation.

THE INSPECTION OF PARALLELISM AND PERPENDICULARITY OF ROLLER BEARINGS

V. L. Riaskov

The inspection of perpendicularity of roller end faces to the generating line of the roller is usually carried out by the method shown in Fig. 1. The roller 1 is placed on the vee-block 2 and pressed with one end face against the stationary stop 3, arranged in the axis of the roller 1. The plunger of the measuring instrument 4 which is displaced from the roller axis by a distance C is pressed against the opposite end of the roller. During the measurement the roller is rotated, and the amount by which it is out of perpendicular is measured as the difference between the largest and smallest indications of the indicator 4.

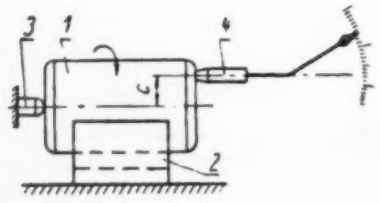


Fig. 1

The measurement errors occurring during such inspection consist mainly of errors due to the inaccurate geometrical form of the rollers (being tapered, oval, barrel-like, etc.), misalignment between the axis of rotation and the axis of the stationary stop, instability of the force pressing the roller against the vee-block and stop, wear of the measuring plunger, etc.

The error due to the incorrect geometrical shape of the roller (taper and barrel-like shape) will always affect the measurement results when the roller is placed on the vee-block, regardless of whether the roller is rotated or not; the ovalness of the roller will affect the measurement results only when the roller in the vee-block is rotated. The deviations from the perpendicular of the roller end face to its generating line amount to several μ. The absolute values of the deviation of the roller from the correct geometrical form are close to the perpendicularity tolerances and have a substantial effect upon the measurement results.

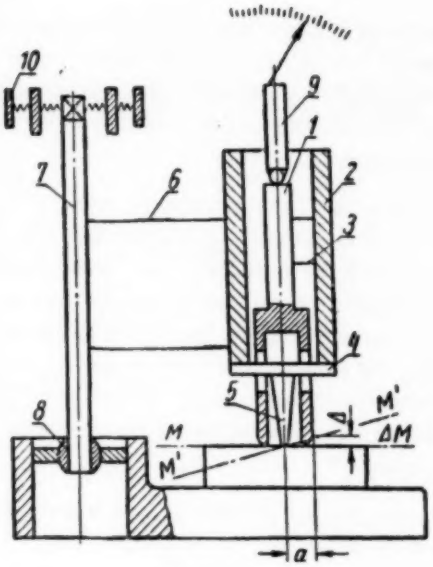


Fig. 2

The error due to the misalignment between the axis of rotation and the axis of the stationary stop are practically unavoidable with the existing inspection method, since there is no means for accurately setting the vee-blocks with respect to the stationary stop 3.

The instability of the force with which the roller is pressed against the vee-block and the stop is due to the rotation of the roller by hand. The deformation of the tip of the stop thus produced is revealed by the oscillations of the gage pointer during the rotation of the roller.

The errors due to the wear of the measuring plunger are due to the fact that those used with the given method devices have as the plunger a needle-shaped hardened steel tip with a small point radius (tens of μ). Owing to the smallness of this radius the contact pressure reaches a considerable size, which brings about an increase of the elastic deformation and distorts the measurement results. Owing to the high contact pressure against the end of the rotating roller a rapid wear of the tip takes place which increases the measurement error and calls for a frequent replacement of measuring tips.

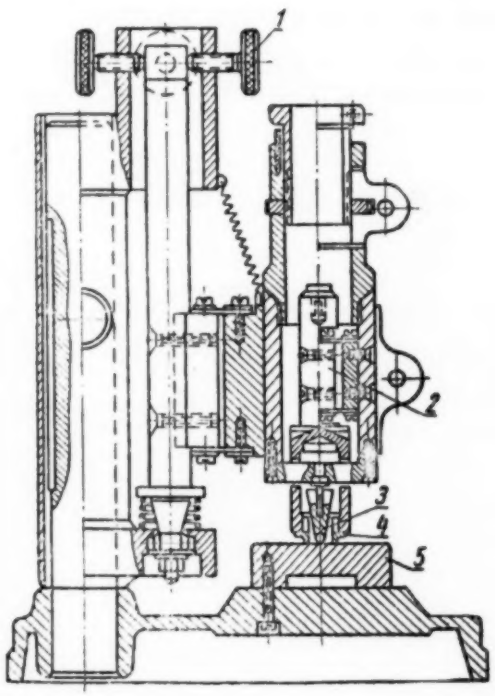


Fig. 3

Apart from the described method of inspection of the perpendicularity of the roller end face to the generating line, which utilizes the rotation of the roller itself in a vee-block, other methods are in use in which the roller is stationary while the stylus of the measuring device travels along the periphery of the roller end face. In this inspection method the error due to the rotation of the roller and the inaccuracy of its setting in the vee-block are eliminated, but the errors caused by the high measuring pressure and the wear of the measuring tip remain, and new errors connected with the unavoidable inaccuracy of rotation of the measuring head are added.

A common and substantial shortcoming of the above method of examining the perpendicularity of roller end faces to the generating line is the low productivity of inspection and the difficulties involved in the automation of inspection processes.

In order to eliminate these shortcomings of the existing methods of inspection of perpendicularity and parallelism we developed a more up-to-date inspection technique, with a high measurement accuracy, which does not require the rotation of the component being tested or of the measuring head.

The schematic diagram of this measurement set-up is given in Fig. 2. The measuring plunger 1 is fixed to the body 2 by means of the spring parallelogram 3. The plate 4 which

is fixed to the body 2 is passed through a rectangular hole in the measuring plunger. The conical stylus 5 is screwed into the plate 4; its axis coincides with the axis of the measuring plunger 1. The body 2 is suspended on the spring parallelogram frame 6 from the adjustment rod 7, the lower end of which is fixed in the three-dimensional pivot 8, and the upper end is held between four screws 10. These screws are arranged in pairs in mutually perpendicularly planes and serve for the accurate setting of the end face of the measuring plunger 1 to the plane MM of the "master gage."

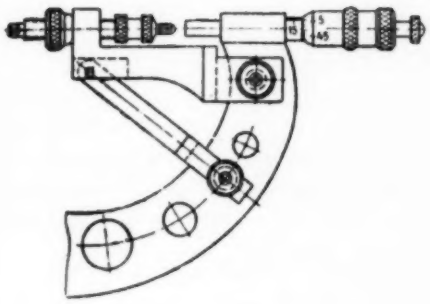
When the end-face plane of the measuring plunger 1 touches the plane MM the stylus 5 is also bound to contact this plane. The plane MM still pressed against the stylus 5 is turned into M'M', then the measuring plunger 1 rises through the distance Δ, which in effect is the absolute value by which the positions of the planes MM and M'M' are out of parallel on the length a, which is equal to half the diameter of the contact part of the measuring plunger 1. This quantity is measured on the scale of the indicator 9.

The design representing the realization of this principle is shown in Fig. 3. The device is adjusted in the following way. A gage block ("master gage") is placed on the table of the device in such a manner that the spherical point of the measuring stylus 3 and the annular measuring tip 4 touch the surfaces of the "master gage;" it is necessary that the tip 4 is in contact with the surface of the "master gage" over the entire area of the ring. However, because of the manufacturing errors of parts of the device, inaccurate assembly, and the misalignment of the interchangeable tip 4 inside the measuring rod 2, it is possible that the ring-shaped point of the tip 4 is not parallel to the surface of the component table 5, and the tip 4 contacts the "master gage" at one point only. The accurate setting of the tip 4 with respect to the surface of the table 5 can be effected by means of the adjustment screws 1 which are placed in pairs in mutually perpendicular planes.

By rotating any pair of screws a minimum indication of the minimeter in each of these planes is reached. This completes the adjustment. When the adjustment is correct, the rotation of any pair of screws 1 in any direction must result in a deflection of the minimeter pointer in the plus direction. In this position the annular point of the measuring tip 4 is parallel to the surface of the table 5. Thereupon the "master gage" is replaced by the work being inspected. When the end faces are out of parallel the tip 4 touches the component surface only at one point, and moves in a vertical direction with respect to the point of contact of the measuring tip 3, through a distance equal to the amount by which the end faces of the work are out of parallel, with the length of radius of the annular point of the measuring tip 4 being the base. The lift of the tip 4 and, consequently, of the measuring rod 2 is determined from the deflection of the minimeter pointer, which indicates the amount by which the end faces of the work being inspected are out of parallel on the base length equal to the radius of the annular point of the tip 4.

A UNIVERSAL DEVICE FOR CHECKING THE MEASURING PRESSURE OF MICROMETERS WITH A MEASURING RANGE EXCEEDING 100 MM

G. B. Manaker



A relatively simple and easy-to-use device suggested by G. N. Churikov (see "Measurement Techniques," No. 1, 1957) is used for checking the measuring pressure of micrometers. However, for checking the measuring pressure of large micrometers, suitable large extension pieces are needed for this device, which cannot, of course, be considered practicable. We suggest, therefore, the use of the existing device for the inspection of indications of large micrometers, in combination with G. N. Churikov's device for testing the measuring pressure, with the following modifications: the tail end is extended to 45 mm and provided with a 1M9 x 1 thread (see Figure). The combined device thus obtained makes possible an easy and rapid adjustment and inspection, and obviates the making of expensive extension pieces.

REPAIR OF TOOTH GAGES

N. V. Sergeev

In repairing tooth gages great difficulties are encountered in lapping the end faces of the measuring legs. In carrying out this operation it is convenient to use a special support block (Fig. 1).

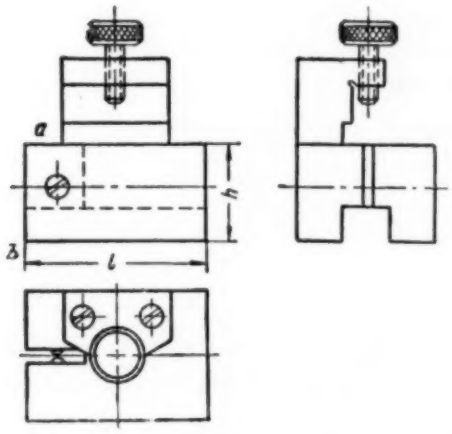


Fig. 1

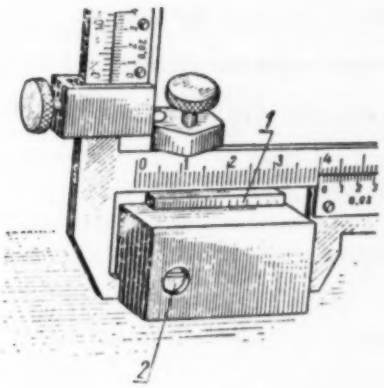


Fig. 2

The surfaces a and b are lapped for parallelism with an accuracy of 0.002 mm. The dimensions h and l are fixed according to the size of the tooth gage; the dimension l is 40-50 mm; and the dimension h should be 1.5 mm smaller than the length of the tooth gage legs, in order to provide for the adjustment of the height by

means of gage blocks. The depth gage (Fig. 2) is set level with the legs by means of a special gage and locked in position. The movable tip is moved out in order to place the tooth gage onto the support block. The depth gage is fitted into the recess of the support. The movable leg is moved toward the support and lapped. The support block and the tooth gage are placed onto the plate, and the gage block 1 inserted into the gap formed between the rod and the block, in such a manner that the legs and the depth gage extend about 0.01 mm below the support plane, whereupon the lapping can be performed.

In order to provide for the stability of the depth gage during the lapping process, it is lightly secured by means of screws 2.

ON THE MEASUREMENT OF TAPER GAGES*

A. N. Dolgushev

The following accurate equation is recommended for the calculation of the dimension B of a built-up gage block stack used in measuring the major diameter of a taper gage by means of a sine bar:

$$B = r_1 + (r_1 + t)\cos 2\alpha + l_1 \sin 2\alpha + D_1 \cos \alpha + \\ + [r_2 \operatorname{tg}(45° - \frac{\alpha}{2})] \sin 2\alpha,$$

where

r_1 is the radius of the main roller of the sine bar;

r_2 is the radius of the support roller;

α is the nominal taper angle;

D_1 is the nominal diameter of the gage in the plane of the rear end;

l is the distance between the axes of the main and support roller measured in the direction parallel to the working plane of the bar; and

t is the thickness of the sine bar.

The taper angle can be measured for the given setup of the gage.

This equation should be included in the relevant instructions.

* Published for discussion.

CONVERSION TABLES FOR HARDNESS NUMBERS

N. P. Slavina

According to the standards in force in the Soviet Union hardness is measured by three methods – Rockwell, Brinell, and Vickers – these being based on the principle of the static impression of a penetrator into the metal under test.

Tables for the mutual conversion of Rockwell, Brinell, and Vickers hardness numbers are often employed in hardness determination in industrial practice. However, the discrepancies existing between these tables makes conversion very difficult. We cannot recommend any one of the many tables published in the technical literature, since the experimental data from which the vast majority of the tables were compiled have not been given in sufficient detail – there is a lack of information on materials, their working, the method of making the measurements and their analysis, etc. Besides this, they contain systematic errors.

TABLE 1

Hardness scale	Hardness from different scales in corresponding units	σ from the corresponding scales, as % of H_D and H_B and in H_R units	Mean	In H_D units
$H_{D_{10}}$	237 316 624	1.7 1.9 1.6	1.7	–
$H_{\mu_{100}}$	254 331 647	5.9 7.2 6.6	6.6	25.2
H_{R_C}	25.5 31.1 41.6 56.0	0.7 0.8 0.4 0.7	0.6	14.1
H_{R_A}	45.8	0.7	0.7	20.3
$H_{R_{30N}}$	41.4 62.9 76.0	0,5 0,5 0,3	0.4	11.3

The Mechanical Laboratory of the D. I. Mendeleev All-Union Scientific Research Institute of Metrology has carried out investigations aimed at the compilation of conversion tables for the steels employed in machine construction. The following steels were selected for investigation: carbon steels – 10, 45, U8A, U10A; silicon-manganese steels – 55S2, 55SG; chrome steels – 45Kh, 1Kh13, 2Kh13; chrome-nickel steels – 12 KhN3A, 12Kh2N4A; and chrome-nickel-molybdenum steels – 25KhM, 5KhNM.

The specimens for hardness measurement were prepared from rolled steel of circular section of diameter 24 to 34 mm. Blanks of length 2 m were cut into specimens 12 mm thick, which were planed; the specimens were then given the usual heat treatment for each mark (hardening with high, medium and low tempering), after which they were subjected to grinding and polishing on cast-iron and glass polishing plates with GOI paste.

Comparative hardness measurements were made on Rockwell instruments of the lever type (scales H_R), on direct-load machines (scales H_D and H_B) and on a PMT-3 instrument (scale H_μ).

As the basic scale with which all the others were compared we chose scale H_D for two reasons: in hardness determination by the impression of a diamond pyramid (scale H_D) a constant ratio is maintained between the load and the square of the diagonal of the impression, i.e., the law of mechanical similarity is observed, and hence the hardness does not depend on the magnitude of the load used to determine it; the diamond pyramidal penetrator enables us to extend the hardness measurements to the whole set of materials – from the softest to the hardest and from the most plastic to the most brittle.

The hardness values from all the scales, with the exception of H_B and H_μ, were taken as the mean of five measurements; the H_B hardness value as the mean of two measurements, and the microhardness H_μ values as the mean of 15 measurements. In the treatment of the experimental data deviations of individual hardness measurements from the mean in a particular specimen were assumed to be accidental.

TABLE 2

$H_{D_{10}}$	H_{R_C}	H_{R_A}	H_{R_B}	$H_{R_{N30}}$	$H_{B\ 10/3000/10}$	$H_{\mu_{100}}$	$H_{D_{10}}$	H_{R_C}	H_{R_A}	H_{R_B}	$H_{R_{N30}}$	$H_{B\ 10/3000/10}$	$H_{\mu_{100}}$
160	—	46.6	80.0	23.0	136	202	490	49.6	75.3	—	70.1	485	498
170	—	48.4	84.4	26.4	147	211	500	50.4	75.7	—	70.7	494	508
180	—	50.0	87.5	29.5	158	220	510	51.0	76.1	—	71.3	504	518
190	—	51.6	90.0	32.3	169	229	520	51.7	76.5	—	71.9	514	529
200	7.0	53.2	92.3	34.7	180	238	530	52.3	77.0	—	72.5	523	540
210	10.5	54.6	94.4	37.0	190	247	540	53.0	77.4	—	73.1	532	550
220	13.9	55.9	96.2	39.1	202	256	550	53.5	77.8	—	73.6	540	560
230	16.8	57.2	98.0	41.0	212	265	560	54.1	78.1	—	74.2	547	571
240	19.4	58.4	99.5	42.8	223	274	570	54.6	78.5	—	74.7	554	582
250	21.7	59.5	—	44.5	234	284	580	55.2	78.9	—	75.2	559	593
260	23.8	60.5	—	46.1	245	293	590	55.6	79.2	—	75.7	563	604
270	25.7	61.5	—	47.6	256	302	600	56.1	79.4	—	76.2	566	615
280	27.4	62.4	—	49.0	267	310	610	56.6	79.7	—	76.7	569	627
290	29.0	63.3	—	50.4	278	319	620	57.0	80.0	—	77.1	570	638
300	30.5	64.1	—	51.8	289	328	630	57.5	80.3	—	77.5	—	650
310	31.9	64.8	—	53.0	300	337	640	57.9	80.6	—	78.0	—	663
320	33.3	65.6	—	54.4	310	345	650	58.3	80.9	—	78.4	—	674
330	34.6	66.3	—	55.5	321	354	660	58.7	81.1	—	78.8	—	687
340	35.8	67.0	—	56.7	332	362	670	59.1	81.4	—	79.1	—	700
350	37.0	67.6	—	57.9	343	371	680	59.5	81.6	—	79.5	—	711
360	38.1	68.2	—	59.0	354	379	690	59.8	81.9	—	79.9	—	725
370	39.2	68.9	—	60.0	365	388	700	60.2	82.1	—	80.2	—	737
380	40.2	69.5	—	61.0	375	397	710	60.5	82.3	—	80.6	—	750
390	41.2	70.1	—	62.0	385	405	720	60.8	82.5	—	80.9	—	764
400	42.1	70.6	—	63.0	395	415	730	61.2	82.7	—	81.2	—	777
410	43.0	71.2	—	63.9	405	423	740	61.5	83.0	—	81.4	—	790
420	44.0	71.8	—	64.8	415	432	750	61.8	83.2	—	81.8	—	804
430	44.9	72.3	—	65.6	425	442	760	62.1	83.4	—	82.0	—	817
440	45.8	72.8	—	66.4	435	450	770	62.4	83.6	—	82.2	—	831
450	46.6	73.3	—	67.2	445	460	780	62.7	83.8	—	82.5	—	845
460	47.3	73.8	—	67.9	455	470	790	63.0	83.9	—	82.8	—	860
470	48.2	74.3	—	68.7	465	479	800	63.3	84.0	—	83.0	—	875
480	49.0	74.8	—	69.4	475	488							

Note. The obtained dependence $H_D - H_{R_B}$ cannot be considered as sufficiently reliable, since individual discrepancies are inadmissibly large and hence render strict statistical treatment impossible.

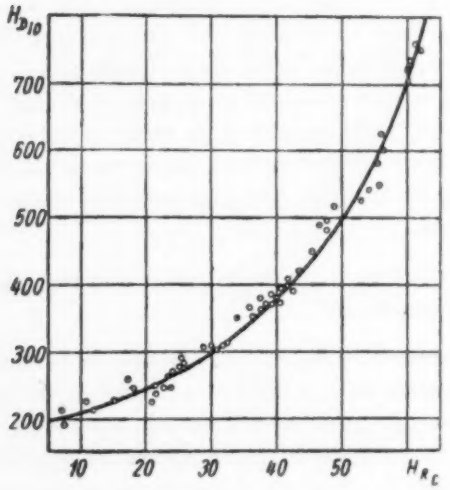


Fig. 1

The accepted distance between two adjacent impressions — at least three impression-diameters or diagonals — prevented one impression's affecting another. As an example we have presented graphically in Fig. 1 the relationship, obtained experimentally for all the investigated marks of steel, between the hardness numbers on the H_{R_C} scale and the hardness numbers on the $H_{D_{10}}$ scale, taken as the basic scale. Similar curves were obtained for all the other hardness scales.

The accuracy of measurement is characterized by the mean square error of the measurement σ and the mean square deviation of the individual measurements σ_Δ from the averaged curve. The latter also shows the inevitable zone of scatter, which is obtained when the H_D scale is plotted in relation to any other hardness scale.

Table 1 gives the values σ and σ_Δ in the case of hardness determination from different scales, compiled on the basis of a large number of measurements on one specimen – at least 30 on the H_R scale , at least 60 on the H_D scale and at least 160 on the H_μ scale.

The averaged curves made it possible to compile Table 2, which gives the hardness values on the $H_{D_{10}}$ scale every 10 units and the corresponding values on the other scales. The conversion of the hardness numbers can be effected with errors σ_Δ indicated in Table 1.

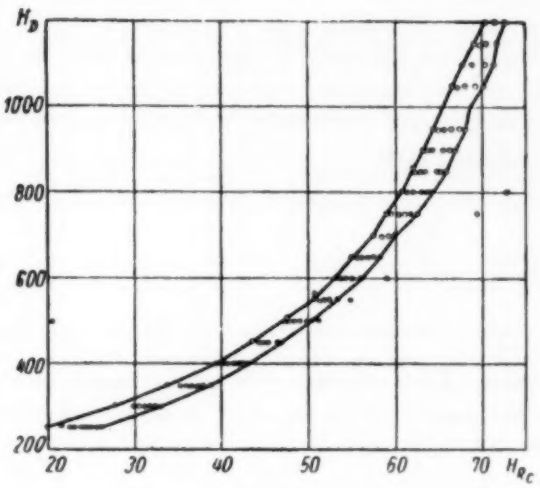


Fig. 2

Investigations of the relationship between micro- and macro-hardness confirmed that only a comparatively coarse relationship could be established, and even then with a large number of restrictions. The latter relate to the method of working, the degree of finish of the surface, the grain size, the homogeneity of structure, etc. The values of micro-hardness determined under a load of P = 100 g are usually higher than the macro-hardness values obtained under a load of 10 kg. The magnitude of the difference depends on the hardness values as well as on the reasons just mentioned. The difference between the micro- and macro-hardness in the H_D hardness range from 160 to 300 was 30-40 units, and in the range 300-600 approximately 15-30 units.

With increase of hardness the difference diminishes, a feature which may be explained by the harder metals' being less susceptible to cold hardening. The increase in micro-hardness by 50-70 units in certain cases as compared with macro-hardness in the range H_D = 600-800 is a result of cold hardening in the mechanical polishing of the specimen. A small number of experiments with electrically polished specimens gave micro-hardness values which practically coincided with the macro-hardness. The experiments were conducted on specimens with $H_D \simeq 400$ and $H_D \simeq 670$.

From the completed investigation of 13 marks of steel we can state that mutual conversion tables for hardness numbers are very approximate and can serve only as a tentative estimate of the properties of metals.

Comparative studies of different conversion tables show that each of them was distinguished by some systematic error of unknown origin, which, strictly speaking, rules out the statistical analysis of the set of tables (Fig. 2). Nevertheless, such an analysis was made. It covered the conversion tables of 12 authors. The obtained values of the mean square deviations were more than twice the values obtained in Table 1. Thus, we have yet another confirmation of the existence of systematic errors in the compilation of the tables by the different authors.

TABLE 3

Hardness values on H_{R_C} scale	Greatest deviations in units	
	H_D	H_{R_C}
25	40	6.5
45	45	3.5
60	75	2.5
70	140	3.5

The zone of scatter for the tables compiled by different authors amounts on the average to 4 H_{R_C} units, i.e., the conversion of the hardness numbers with the accuracy stipulated by GOST 7038-54 cannot be attained.

SUMMARY

1. The accuracy of conversion of hardness numbers from one scale to the other cannot be evaluated from the mean square errors of the measurements; we must take into account the zone of scatter of the hardness values which is due to the nonequivalence of the relationships examined and to the influence of overlooked systematic errors. The accuracy of conversion can be estimated from the mean square deviations σ_Δ of the results of individual series of measurements from the averaged curve.

2. An investigation of 12 conversion tables compiled by different authors indicates the presence of systematic errors in the compilation of each of them. Hence, none of the tables has any advantage over the others and none can be recommended. Their union into a single conversion table is equally impossible.

3. Conversion of hardness numbers from one scale to another is permissible for a tentative estimate of the properties of metals, but not for accurate work, and is only permissible for tables compiled for a restricted range of metals and alloys used in a particular branch of industry.

ERROR OF VIBROMETER READING DUE TO ITS REACTION ON VIBRATING SURFACE

I. I. Kliukin

Measurement of vibration in solid bodies (in brief, vibrometry [1]) is assuming ever greater significance in connection with work on noise prevention in industry and transport, and in studies on sound insulation and sound absorption in building.

In the design of instruments for measuring vibration (vibrometers) special measures are taken to reduce the error of the readings and to ensure a more or less constant sensitivity over a wide range of frequencies. These measures mainly relate to the sensitive element of the vibrometer. Designers of vibrometers and workers involved in vibrometry sometimes do not suspect how a characteristic such as their mass may greatly affect the error in the readings of vibrometers which are in contact with the vibrating surface (and such vibrometers are most often used in practice).

The power of sound and vibration sources is limited and hence the reaction of contact vibrometers of finite mass on a vibrating surface causes a reduction in vibrations at the point of application of the vibrometer and, hence, a diminution in the vibration level recorded by the vibrometer. This reduction, as we will see later, is particularly large at medium and high frequencies of the acoustic range. There it may exceed 10-15 db, which increases the error of the vibrometer readings of several hundred percent as compared with vibrometer readings determined from a consideration of its frequency calibration curve.

For vibrometry in the acoustic range two types of vibrometers are mainly used at the present time.

1. Vibrometers of the piezoelectric type, which are receivers of particle acceleration. Since this is proportional to the square of the frequency in the case of harmonic vibrations, these vibrometers can be successfully employed to measure small vibration levels right up to frequencies of 10 kc or more.

The best instruments of this type are the miniature ("point") vibrometers [2, 3]. Their sensitive element – a crystal or packet of crystals of piezoelectric material – is of small size and is mounted directly on the bottom of the light protective casing of the vibrometer so that it covers the whole area of the bottom of the casing. This prevents resonance of the bottom of the casing, which would distort the frequency response of the vibrometer. The resonance frequency of the piezocrystal itself exceeds 10-15 kc. The mass of such vibrometers is usually less than 20-30 g, but even such a small mass may produce definite distortions of the vibrometer readings at high frequencies.

In the vibrometry of machines there is often employed a somewhat more sensitive piezoelectric vibrometer, in which the working element consists of two joined plates of piezoelectric material (bimorphous element), attached by a bracket to the vibrometer casing. The mass of such a vibrometer varies from 100 to 500-600 g, depending on the design. Reliable measurements at frequencies up to 1-1.5 kc can be made with instruments of this design, but at higher frequencies the error increases owing to the resonance of the piezocrystal and the bottom

of the vibrometer casing. Such vibrometers are in large-scale production by a number of American and English firms. In the USSR a vibrometer of this design has been developed by the Institute of Radio Reception and Acoustics.

2. Vibrometers of the electrodynamic type (induction type) are receivers of particle velocities in the main working frequency range and have a low resonance frequency. Reliable measurements with these vibrometers are possible up to 1 kc or more, but at high frequencies they are less sensitive than piezoelectric vibrometers. As examples of electrodynamic vibrometers we may mention that developed by M. S. Antsyferov [4] and the vibrometer of the Philips firm (Holland). The mass of electrodynamic vibrometers varies from several hundreds of grams to 1 kg or more, depending on their design.

Effect of vibrometer mass on error in measuring flexural vibrations of fixed frequency. In the propagation of sound vibrations through buildings and other structures the main role is taken by flexural vibrations, which transmit the main proportion of the vibrational energy. Hence in vibrometry the greatest interest attaches to the evaluation of the error in measuring vibration levels in the case of the propagation of flexural vibrations.

Let a travelling plane flexural wave be propagated in any very long body – plate or rod. Using symbols, we can write the transverse displacement at any point in the plate in the form:

$$\xi = \xi_0 e^{j\omega t}. \tag{1}$$

where ξ is the amplitude of the transverse displacement,
ω is the angular frequency of the vibrations,
t is the time.

When a vibrometer (Fig. 1) is placed at this point in the plate or rod there arises a reflected wave possessing a transverse displacement ξ_{ref}. In determining the magnitude of the vibrational force at the point of application of the vibrometer it is convenient to use the concept of impedance as applied in acoustics, this being the total mechanical resistance of the body to vibrational movement and is equal to the ratio of the vibrational force to the produced particle velocity of the body. The force acting on the vibrometer on the side of the vibrating body is

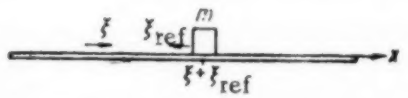


Fig. 1. Plate with vibrometer mounted on it.

$$F = -(\dot{\xi} + \dot{\xi}_{ref}) z_b = -j\omega(\xi + \xi_{ref}) z_b \tag{2}$$

where $\dot{\xi}$ and $\dot{\xi}_{ref}$ are the particle velocities in the incident and reflected wave,
ξ_{ref} is the displacement in the reflected wave,
z_b is the impedance of the vibrometer in a direction perpendicular to the surface of the body.

This force must be equal to the reaction of the vibrometer on the vibrating body:

$$F_1 = \dot{\xi}_{ref} z_T = j\omega \xi_{ref} z_T, \tag{3}$$

where z_T is the impedance of the body (rod or plate) in relation to the flexural vibrations.

The degree of attenuation of the plate vibrations by the vibrometer in a transverse direction, i.e., the ratio of the amplitude in the incident wave (required value) to the amplitude at the point of application of the vibrometer, is equal to:

$$N = \frac{\xi}{\xi + \xi_{ref}}.$$

From (2) and (3) the complex value for the attenuation of vibrations can be represented as

$$N = 1 + \frac{z_b}{z_T}. \tag{4}$$

This value for a fixed frequency of vibrations will be the same both in the case of a particle displacement receiver in contact with the surface, and in the case of particle velocity or acceleration receivers.

Outside the region of resonance frequencies of the moving system of the vibrometer its impedance is purely inertial, i.e., $z_b = j\omega m$, where m is the mass of the vibrometer. In vibrometers of the electrodynamic type the main working range of frequencies lies above the resonance frequency of the moving system. When the resonance frequency is sufficiently remote, the mass of the moving system of the vibrometer is dynamically "isolated" from the vibrometer casing, and hence the mass m, which attenuates the plate vibrations, is merely the mass of the instrument casing. For piezoelectric vibrometers the working range lies below the resonance of the sensitive element, and by mass m we mean the whole mass of the instrument, i.e., the mass of the casing, piezoelectric element and the parts attaching the latter to the casing.

The impedance z_T depends on the nature of the body in which the vibrations are propagated. For the commonest case of an "infinite" plate excited in the middle, this impedance is equal to [5]:

$$z_T = 8h^2 \sqrt{\frac{E\rho}{12(1-\sigma^2)}}, \tag{5}$$

where h is the thickness of the plate,

E, ρ, and σ are Young's modulus, the density and Poisson's ratio of the plate material.

After substituting expressions for z_b and z_T in (4) and taking the modulus, the expression for the attenuation of the transverse vibrations of the plate at the point of application of the vibrometer takes the form

$$L = 10 \lg (1+\beta^2) \text{ db} \tag{6}$$

where

$$\beta = \frac{\pi\sqrt{12}}{4} \sqrt{\frac{1-\sigma^2}{E\rho}} \frac{mf}{h^2}. \tag{7}$$

Here f is the frequency of vibrations.

If the vibrometer registers the vibrations in a direction transverse to the plate surface, the given values of the attenuation of vibrations must, in effect, represent the corrections which it is necessary to introduce into the vibrometer readings in order to obtain the true values of the vibration levels of the plate at the given frequency.

As we see, the distortion of the vibrometer readings depends mainly on the thickness of the plate under test. The vibrometer mass and the measurement frequency have an equal influence on the vibrometer readings.

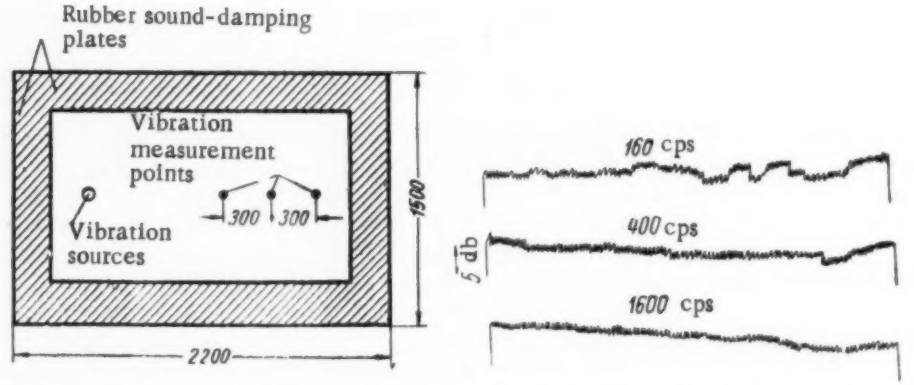


Fig. 2. Form of duralumin sheet tested and curves showing reduction of sound levels along the sheet.

It is of interest (and this may be proved in a more general form) that the degree of attenuation of transverse vibrations of plates and rods by the vibrometer does not depend on the values characterizing the resistance of the vibrometer to a flexural moment. Hence, the distortion of the readings of any vibrometer will be the same for either rigid attachment to the vibrating body or when it is mounted freely on the body. Here, as in the case of deduction (6), it is assumed that the length of contact of the vibrometer with the plate or rod is small in comparison with the length of the flexural wave in them. The length of the flexural wave may be determined from the formula:

$$\lambda_u = 1.35 \sqrt{\frac{h}{f} \sqrt{\frac{E}{\varrho}}} \text{ cm}. \tag{8}$$

As already mentioned, the given deduction is valid for a traveling flexural wave. In plates of attenuating materials (concrete, wood) the condition that standing waves should be absent is easily realized in bodies of relatively small size, not exceeding a few lengths of the flexural waves. With insufficiently large metal plates and rods, which possess little attenuation, the condition that standing waves should be absent during measurements can be fulfilled by installing strips of damping materials on the ends of the plates or rods, and thus reducing the reflection of vibrations from the ends of the bodies. When standing waves are present the attenuation of the vibrations by the vibrometer (as also the sound level recorded by the vibrometer) will depend on the point of application of the vibrometer relative to the nodes and antinodes of the standing wave of a particular frequency.

For experimental verification of the effect of the vibrometer mass on the result of vibration measurements we should have had two (or more) vibrometers of different mass but with the same sensitivity and frequency response. In view of the difficulty of constructing such vibrometers we employed the following method: measurements were first made of the vibration of a particular plate at different frequencies from a constant vibration source. For the measurements we used a "point" piezovibrometer of mass 25 g. The measurements were then repeated when heavy weights were mounted on the vibrating surface or on the vibrometer itself, thus simulating the attachment of vibrometers of corresponding mass. From the results of a comparison of the amplitudes of the plate vibrations recorded by the vibrometric system with the application of different weights we determined the relative attenuation of the plate vibrations by vibrometers of different mass.

The plate in which the vibrations were excited consisted of a sheet of duralumin 1.5 x 2.2 m, and 1.5 mm thick. The vibration source was a device in which a number of strikers fell several times a second on the investigated plate. In this way vibrations in a wide range of frequencies were excited in the plate.

To reduce the reflections from the ends of the plate we placed round its perimeter broad strips of thick rubber which was able to damp the sound vibrations. As we see from the trace on the logarithmic recorder of the levels, the vibrations at different frequencies diminished uniformly along the plate (Fig. 2). Hence, the role of standing waves was reduced to a minimum.

Measurements of the vibration levels were made at three points 30 cm apart on the length of the plate. The levels were recorded in frequency bands equal to a semi-octave. The total frequency range of the measurements was 100-2000 cps. A few measurements were also made at frequencies above 2000 cps.

In Fig. 3 we show the frequency curves obtained from (6) for the attenuation of vibrations of the test plate by vibrometers of different mass. We can see that the attenuation of vibrations, particularly at high frequencies, may become quite considerable.

The values of the attenuations in Fig. 3 are given in decibels. In order to obtain the relative attenuation of the plate vibrations at a particular frequency by two vibrometers of different mass we must take the difference of the ordinates of the curves for the respective masses at this frequency. From the relative attenuation, which will also be expressed in decibels, we can find, when required, by how many times one vibrometer attenuates the vibrations more than another.

It is most convenient to compare the attenuation of vibrometers of different mass with the attenuation due to the lightest vibrometers. The curves in Fig. 4 were obtained from the graph in Fig. 3 by subtracting the ordinate of the curve for m = 25 g from the ordinates of the calculated curves for different m. The solid curves correspond to the experimental loads 100 and 1000 g, which are equivalent to vibrometers of corresponding mass. Here we give the experimental data obtained by taking the mean difference of the vibration levels from the three measuring points when the loads 100 and 1000 g were applied at these points, and without loads.

As we can see, the values of the attenuation by vibrometers of finite mass, calculated from (6), are greater than those found by experiment. We should, however, take into consideration the fact that the vibrometer in the tests was held on the vibrating surface by hand and thus its actual mass was more than 25 g. The exact value of the additional mass of the fingers involved in the vibrations is difficult to determine. If we assume that this additional mass does not exceed 25 g, the total mass of the "point" vibrometer will be 50 g, the vibrometer and 100 g load together will be 125 g and the vibrometer and 1000 g load will be 1025 g. The corresponding curves for the attenuation of the plate vibrations and the difference in the attenuations by vibrometers with such masses are given by the broken lines in Figs. 3 and 4. The lower of the obtained calculated curves in Fig. 4 (for vibrometer of mass 100-125 g) reproduces fairly well the experimental results. For a vibrometer of mass 1000 g the calculated attenuation of vibrations at lower frequencies exceeds that found by experiment. However, the general behavior of the calculated frequency curves is in good agreement with the position of the experimental points. The calculated and experimental values of the attenuation of vibrations at frequencies above 500 cps are also in good agreement. We note that at frequencies up to 2000 cps approximately the same attenuation of vibrations is obtained when the load is rigidly fastened to the plate and when it is mounted freely on the plate, and also when the load is suspended on the vibrometer (in this last case the results are a little less stable).

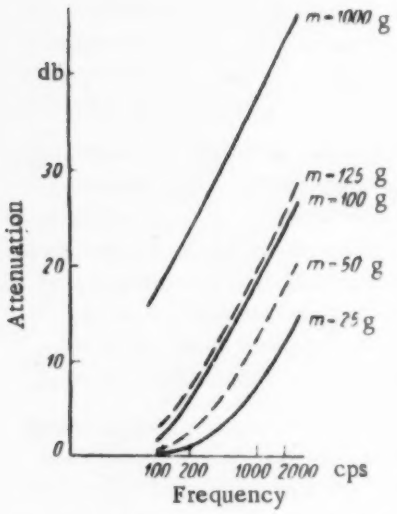


Fig. 3. Calculated attenuation of vibrations of 1.5 mm thick duralumin sheet by vibrometers of different mass.

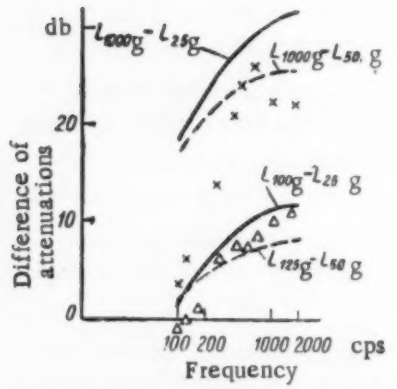


Fig. 4. Comparison of calculated and experimental results for the degree of attenuation of vibrations of a duralumin sheet by vibrometers of different mass.

We carried out a few measurements of the attenuation of the plate vibrations by loads of different mass at frequencies above 2000 cps. At these frequencies we do not observe any clear relationship between the attenuation and the frequency. The value of the attenuation varies between 2-3 and 15-20 db, i.e., it is less than the calculated attenuation values. One of the possible causes of the divergence of the experimental and calculated values is that at high frequencies the length of the flexural wave in the plate is commensurable with the dimensions of the loads (and at frequencies above 500 cps even with the dimensions of a "point" vibrometer), and hence one of the basic conditions* on which (6) is based is not met. For measurements at high acoustic frequencies there is also a characteristic error due to the instability of contact between the vibrometer and the vibrating surface. In order to obtain more uniform results at these frequencies the vibrometer must be screwed on to the surface of the body (sometimes magnets are employed for holding the vibrometer close to the surface, but it is clear from what has been said that they will produce an additional attenuation of the vibrations).

As a whole, the results of experiments show that in view of the complexity of the interaction of the vibrometer and vibrating surface the given formulas for the attenuation of vibrations mainly give a qualitative estimate of the magnitude of the error in measuring vibrations by vibrometers of different mass. In certain cases, the formulas could possibly be used to determine the approximate correction to the vibrometer readings, but their main purpose is to determine in what range of frequencies a vibrometer of given mass can be employed without introducing errors.

A calculation from (6) shows, for instance, that for a hollow concrete beam ($h = 2$ cm, $E = 2 \cdot 10^{11}$ d/cm^2, $\rho = 2$) the use of a vibrometer of mass 1000 g is not permissible, since at frequency 2000 cps the attenuation of

* The failure to satisfy this condition is, among other things, a cause of the additional errors in vibrometers with large bases.

the vibrations exceeds 7 db. In the measurement of vibrations of a wooden board 1 cm thick by a vibrometer of mass 100 g, the calculated attenuation of vibrations at frequency 2000 cps has a value 5-6 db (i.e., the amplitude of the vibrations is halved). Hence, such a vibrometer is unsuitable for the measurement of the absolute vibration levels of wooden boards of the thickness stated in a large range of frequencies. Especially large errors occur in the measurement of vibrations of thin plates and rods, including those made of metal, as was seen from the calculated and experimental example given.

Attenuation of flexural vibrations by vibrometer in the frequency range $f_L - f_u$. In the vibrometry of machines the mean vibration levels in a particular frequency range are often measured. For such measurements we use vibrometric systems consisting of a vibrometer and a wide-band amplifier with a recording instrument. If the frequency spectrum of the measured vibrations contains any specially intense component of particular frequency or a narrow region of frequencies with very intense components, the correction for the attenuation of vibrations will be mainly determined by the degree of attenuation of vibrations at that frequency or in that narrow frequency region. However, in the case where the spectral vibration levels in a particular frequency range uniformly diminish or increase with frequency, the averaged attenuation in the frequency range due to the reaction of the vibrometer is automatically included in the mean value of the vibration level recorded by the vibrometer in this range.

For an understanding of the possible nature of the errors resulting from this, we will consider the following points.

In the vibrometric system, the readings of which are proportional to the energy sum of the frequency components of the vibration, while the reaction of the vibrometer on the body is negligible, the recorded vibration level in the frequency range $f_L - f_u$ is equal to:

$$A = \sqrt{\frac{1}{f_u - f_L}\int_{f_L}^{f_u}\left[A_0\left(\frac{f_u}{f_L}\right)^n\right]^2 df}. \tag{9}$$

where n is an index indicating the degree of change with frequency of the spectral level of vibrations, and A_0 is the spectral level at frequency f_L.

For a system with a frequency-constant response to the investigated parameter of the vibration process, $n = 1$ will correspond to a vibration spectrum with a rise of levels of 6 db/octave, $n = 0$ to a uniform spectrum and, $n = -1$ to a falling spectrum with a change of level of 6 db per octave, etc.

For a real vibrometric system with a vibrometer of finite mass an expression for the mean recorded vibration level A_1 is obtained, if we introduce under the integral the frequency function $\varphi(f)$ of the attenuation of the vibrations of the given body by the vibrometer. In particular, for a long plate the function $\varphi(f)$ is the expression under the logarithm sign in (6).

The expression for the mean attenuation in the frequency range $f_L - f_u$ by a vibrometer of finite mass has the form

$$L_c = 20 \lg \frac{A}{A_1} = 10 \lg \frac{\int_{f_L}^{f_u} (A_0 f^n)^2 \, df}{\int_{f_L}^{f_u} \frac{(A_0 f^n)^2}{\varphi(f)} \, df} \text{ db} \tag{10}$$

The result of integration in (10) for plates and for rods is greatly simplified if we assume that $f_u \gg f_L$, which is often the case in practice.

For a long rod the expressions for the attenuation of vibrations in a frequency range with different kinds of vibration spectra is obtained in the form

$$L_{\underset{n=1}{c}}=10\ \lg\left(\frac{p^2}{12}f_{\text{u}}\right)\ \text{db}$$

$$L_{\underset{n=0}{c}}=10\ \lg\left(\frac{p^2}{8}\ \frac{f_{\text{u}}}{\ln\frac{f_{\text{u}}}{f_{\text{L}}}}\right)\text{db} \tag{11}$$

$$L_{\underset{n=-1}{c}}=10\ \lg\left(\frac{p^2}{4}f_{\text{L}}\right)\ \text{db}$$

where

$$p=\frac{\sqrt[4]{2\pi\sqrt{12}}}{\sqrt[4]{\text{E}\,\rho^2}}\ \frac{m}{b\,h^{3/4}}. \tag{12}$$

Here, b is the width of the rod, and the other symbols have occurred earlier.

Expressions (11) are valid on condition that

$$4pf^{3/4} \ll p^2 f \gg 8. \tag{13}$$

A comparison of (13) with (12) shows that the condition (13) corresponds to large values of vibrometer mass and measurement frequency and to small thicknesses of the rod, i.e., it is valid in the case of large values of attenuation of the rod vibrations by the vibrometer, where the greatest errors in measuring the mean vibration level occur.

It can be seen from (11) that, depending on the kind of vibration spectrum, the mean attenuation of rod vibrations in the frequency range by a vibrometer of finite mass is determined either by the value of the upper frequency of the range (n = 1) or the value of its lower frequency (n = − 1), or by the value of both frequencies (n = 0). For a plate the quantitative relations will be different, although the nature of the dependence of the mean attenuation on the values of the boundary frequencies for different n will still be the same.

In the case of a falling continuous vibration spectrum the mean correction in the frequency range for the attenuation of vibrations by a heavy vibrometer may be less than the similar correction for vibrations with an increasing spectrum measured by a less heavy vibrometer. This can be explained physically by the fact that with an increasing vibration spectrum the mean vibration level recorded by the vibrometer is determined largely by the high frequency components, for which the reaction of the vibrometer and the attenuation of vibrations produced by it are large.

As an illustration of the foregoing, we will consider a numerical example. By means of a heavy vibrometer two measurements are made of the mean vibration level of a long rod in the frequency range 100-4000 cps. In the first measurement the vibration source is such that the vibration spectrum of the rod has a rise of 6 db per octave, and in the second measurement a fall of 6 db per octave. The mass of the vibrometer in the first case is a third of that in the second, and the response of the vibrometers in relation to the measured parameter of the vibration process does not depend on the frequency. We require to estimate the ratio of the corrections to the vibrometer readings in these two measurements.

From (11) the difference in the mean values of the attenuation of vibrations in the frequency range for n = 1 and n = − 1 (in db) is:

$$L_{\underset{n=1}{c}}-L_{\underset{n=-1}{c}}=10\ \lg\left[\left(\frac{p_{n=1}}{p_{n=-1}}\right)^2\frac{f_{\text{u}}}{f_{\text{L}}}\ \frac{4}{12}\right]\ \text{db}$$

On the basis of (12) the ratio of the values of p for each rod can be replaced by the ratio of the vibrometer masses. Substituting the conditions of the example in the last formula, we obtain:

$$L_{c\,n=1} - L_{c\,n=-1} = 10 \lg\left[\left(\frac{1}{3}\right)^2 \frac{4000}{100} \cdot \frac{4}{12}\right] \simeq 2 \text{ db}.$$

Thus, in the first case the correction to the mean vibration level recorded by the vibrometer in the frequency range is a little more than in the second, although the weight of the vibrometer is less. This seeming paradox is due to the difference in the nature of the vibration spectrum. If the lower frequency limit of the effective range of the vibrometers is lowered to 10 cps the difference in the vibrometer readings would exceed 10 db.

Another source of errors in the measurement of the mean vibration level in a frequency range is nonuniformity of the frequency characteristic of the vibrometer.

The given expressions and calculations are intended to show that for a varying vibration spectrum measurements of the mean sound levels in a frequency range by vibrometers of finite mass are more of a qualitative nature and may lead to significant errors as a result. Hence, in all cases a frequency analysis is preferable to such measurements.

SUMMARY

1. Real vibrometers of finite mass exert a considerable reaction on the vibrating body. The magnitude of the reaction, and hence the error in the vibrometer readings, increases with frequency. The error is particularly large in measurements of the vibration levels of thin plates or rods by heavy vibrometers.

The order of magnitude of the error in vibrometer readings due to its reaction on a plate in which flexural waves are being propagated can be determined from the formulas given.

2. In measurements of mean vibration levels in a frequency range the error due to the reaction of the vibrometer on the vibrating body is inseparable from the result of the measurements. The magnitude of the error largely depends on the nature of the frequency spectrum of the measured vibrations.

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AN AMPLIFIER FOR STRAIN MEASUREMENT WITH WIRE RESISTANCE GAGES

K. V. Semenov and V. V. Spirov

The introduction of methods of strain measurement employing wire resistance gages in the everyday work of factory laboratories and institutes has been held up owing to the lack of universal electronic equipment. The demands made on such equipment have been set forth in [1].

The carrier-frequency amplifiers employed in strain measurement are often unsuitable in full-scale investigations of strains in machine and structure components.

In several cases of strain measurement it is possible to do without amplifying equipment by employing highly sensitive loops, gages of material with a high sensitivity factor, low-ohmic wire gages with grids connected in parallel, etc. However, when highly sensitive loops are used the frequency range of the stresses registered is reduced.

Below we describe an ac amplifier which allows the registration of stresses at many points at frequencies corresponding to the limits of application of loop oscillographs. The amplifier differs from the amplifiers usually employed in strain measurement in the following features: the gage bridge is supplied by direct current; there is no phase-sensitive channel; rapid switching of the gage bridge is possible.

The amplifier circuit is shown in Fig. 1.

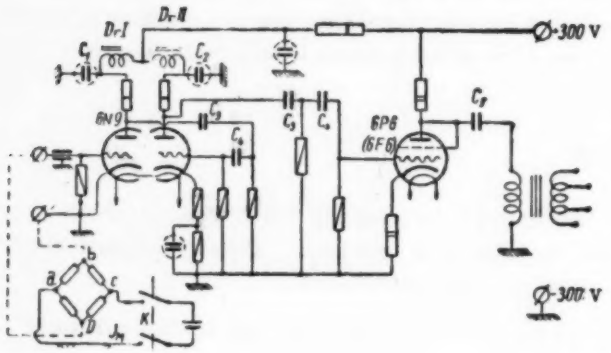

Fig. 1

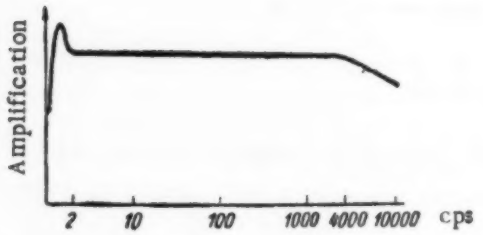

Fig. 2

For eliminating the effect of other amplifiers operating from the common power supply, the filters C_1 – DrI and C_2 – DrII are incorporated.

For correction of the amplifier characteristic for low frequencies bridging circuits between the first, second, and third stages incorporate dual resistor coupling. This allows a shift of the flat portion of the characteristic toward the low frequencies.

The anode circuit of the output tube incorporates a capacitor C_2 and an output transformer with a large number of coils, constituting an oscillation circuit tuned approximately to a frequency of 1 cps. This connection of the output transformer gives an additional shift of the amplifier characteristic toward the low frequencies.

The tapped step-down coil of the output transformer is designed for the connection of loops of types I, IV, V, and VIII.

The amplification factor is more than 1000.

The amplifier characteristic is shown in Fig. 2.

Use of amplifier for measurement of mechanical strains. When the power supply to the gage bridge is switched on the amplifier will receive a voltage from the measuring diagonal of the bridge, and as a result there will occur pulsed variations of the anode currents of the tubes and the current in the loop. The nature of the current variations is shown in Fig. 3.

When the supply is cut off the process is repeated but the direction of the currents will be reversed. It is obvious that the amplitude of the loop current pulse is proportional to the voltage on the measuring diagonal of the gage bridge. The nature of the loop current variation is due to the presence of high inductance and capacitance in the output stage.

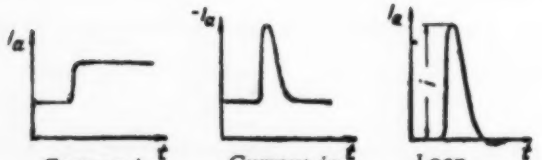

Fig. 3

This variation in the loop current can be used for pulsed registration of static and slowly changing strains. Figure 4 shows an oscillogram of the pulsed registration of strains at 13 points. The rate of registration is approximately 4 pulses per second. The loop is connected up through a special contact device described below.

For registration we can use the initial upper portion of the descending branch of the curve of the loop current (Fig. 4).

This method of measurement permits the registration of both the constant and variable components of the strain.

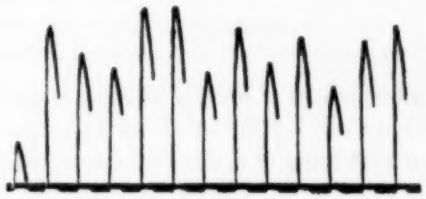

Fig. 4

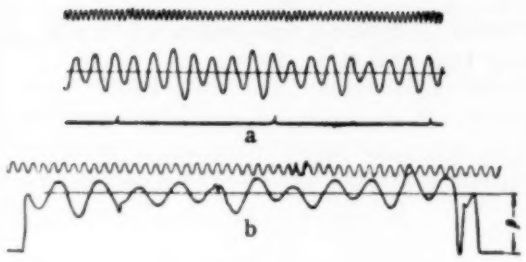

Fig. 5

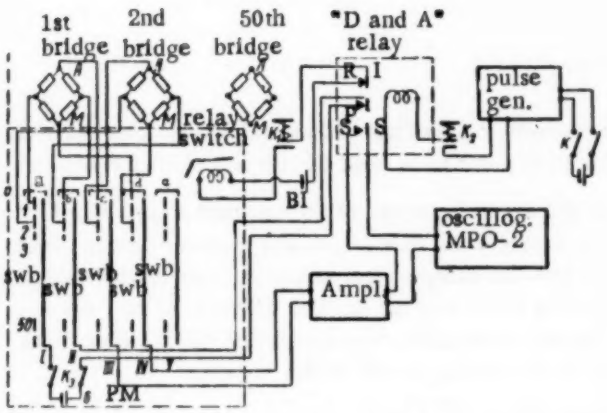

Fig. 6

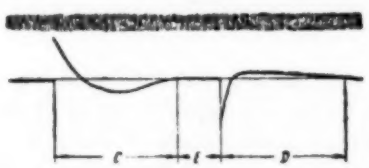

Fig. 7

For this purpose the switching-in of the supply and loop must occur at a time corresponding to the upper portion of the current curve (Fig. 3). The oscillograms in Fig. 5 may serve as an example. Figure 5, a shows the oscillogram of strains in the cheek of the crankshaft of an internal combustion engine during a continuous recording of strains (only the variable component). Figure 5, b shows an oscillogram of strains when the loop is connected for only $^1/_{10}$ of a second, i.e., at a time corresponding to the upper "landing" of the current curve.

The distance P on the oscillogram corresponds to the constant component of the strains.

Switching of measurement points. For the successive registration of strains at many points by means of a single amplifier and a loop oscillograph it is convenient to employ switching systems incorporating the high-speed step-by-step switches ATS. The switch action is initiated by a hand button or by a pulse generator.

When the periodic switching of the bridges takes place large current pulses, which do not characterize the measured deformations, appear at the amplifier output. The amplitude of the current pulses is usually much greater than the strain registration currents, and this can be dangerous for the loops. The switching-on of the bridge supply, and also of the oscillograph loop must take place after the fall of the current pulse produced by connecting the bridge to the amplifier. Such connection conditions are achieved by means of a "delay-advance" relay.

The relay operates from a special pulse generator, the frequency of which can be varied smoothly or by steps in the range 0.25 to 20 cps.

A block diagram of the registration of stresses with the switching of the measurement currents is shown in Fig. 6.

In the diagram the switch with brushes a, b, c, and d is in the zero position. The buttons K_1 and K_2 are paired and have a lock. When key K is switched on the pulse generator begins to operate. By pressing the buttons K_1 - K_2 (button K_1 closes a little earlier than K_2) the battery B is connected to the winding of the relay switch; the switch brushes then shift, connecting the first bridge to the amplifier input. At this moment the contacts R-I of the "delay and advance" relay are broken and stop the switch brushes. A large current pulse (see portion C on Fig. 7) is obtained on the amplifier output. Next the contacts P-M of the bridge supply are made, finally the contacts S-S are made, and these connect up the loop.

Registration of the stress on film is effected from portion E of Fig. 7 after the passage of the pulse from the generator. The contacts S-S are first to break, disconnecting the loop, and here there occurs the advance of the

disconnection of the loop (portion D drops out); the bridge supply is then cut off and contacts P-I are made, thus supplying power to the relay switch. The brushes move into the next position and the process is repeated.

SUMMARY

The use of a fast switching apparatus and the amplifier described makes it possible to register strains during a relatively short time at many points. The described amplifier circuit was applied to the oscillography of strains in investigations on machines. This gave results in good agreement with those of theoretical calculations and with the experimental data obtained by other methods.

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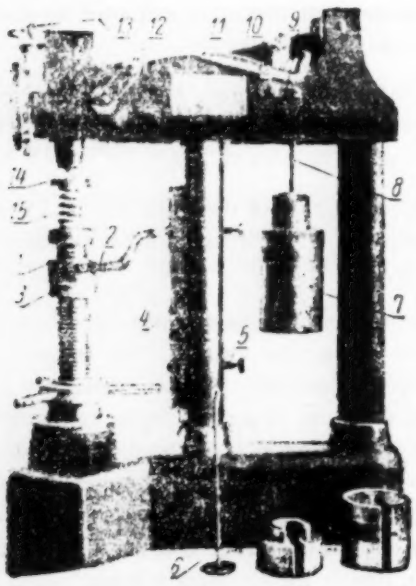
ATTACHMENT FOR TESTING SPRINGS ON THE TK HARDNESS TESTER

M. I. Malakhov

In the Tambov factory "Komsomolets" there has been developed, constructed and introduced into practice an attachment for the TK hardness tester, which enables this instrument to be used for the testing of springs.

With the help of slide blocks a nut 1 is screwed on to the elevating screw of the instrument (see figure) and to this nut is rigidly fastened a pointer 2, which serves to indicate the free length and degree of compression of the spring. The nut carrying the pointer is fixed on the elevating screw by a locking screw and nut 3. The diamond or ball tip in the spindle opening is replaced by a supporting disk 14 on a shank which is held by the locking screw on the spindle.



A 250-mm-long scale 4 with millimeter divisions is attached by means of clamps 5 to the instrument pillar.

The loading lever of the instrument engages with one end of the indicator 11, which can rotate round an axle 10, fixed at the base of indicator 9.

When the pointer is in the zero (neutral) position, a mark is made on the case of the instrument opposite the tip of the pointer. To fix this mark accurately a dynamometer must be used. The dynamometer is mounted on the anvil of the elevating screw, and by means of the handwheel it is raised till it contacts the supporting disk 14. Then, by means of the screw and the dynamometer a load of 10 kg is created on the spindle in order to compress the contained spring (which develops a force of 10 kg in the compressed state) and to fix the mark on the casing. In order to adjust the scale on the pillar of the instrument a gage block of 40 mm, say, is laid on the anvil. By means of the handwheel the elevating screw of the instrument carrying the gage block is raised upward till the pointer 11 reaches the zero position, i.e., is on the mark. After this the zero line on the scale is brought in line with the supporting plane of disk 14. The pointer 2 is set so that it lies opposite the reading corresponding to the length of the gage block.

Before operation the transmission lever of the indicator is freed from the travelling spindle of the instrument by means of a special clamp 13, which completely disconnects the indicator. The handle 12 is set so as to free the load lever from the catch and apply the load. The instrument is then ready for work. Testing of springs can be carried out in two ways, depending on the technical data required: the deformation as a function of the load or the load as a function of the deformation. In determining the deformation relative to the load a fixed weight 7 is hung on the suspension rod 8 (6) of the load lever. Then the test spring 15 is placed on the anvil, and by means of the handwheel is raised until it contacts the supporting disk. The full length of the spring is determined by taking the scale reading of the pointer. It must be borne in mind that this length is 1 mm greater than the actual length of the spring in the free state. The difference of 1 mm is due to the fact that the zero (neutral) position of the pointer was set with a load of 10 kg on the spindle and the spring in the spindle was in a state of compression, while in the measurement of the total length of the spring in the free state the spring in the spindle was free. The spring is then compressed till the pointer reaches the zero position. The second reading is now taken and this reading corresponds to the length of the spring in the compressed state. The difference in the readings gives the value of the deformation.

In determining the load relative to the deformation or length of the spring in the compressed state the spring is mounted on the anvil, and by means of the handwheel and elevating screw is compressed to a length corresponding to the required length in the compressed state. In this case the load lever of the TK instrument is raised and the pointer 11 is lowered. By adding weights to the suspension rod, the force of the spring is counter-balanced until the pointer 11 occupies the zero position.

The TK instrument can also check the residual deformation of a spring after it has been compressed until the coils meet.

On the described instrument, we can test springs up to 150 mm in length and with loads of 10 to 150 kg.

SUMMARY

The attachment is easily operated, gives readings to an accuracy of the order 0.1 mm, and is of simple construction.

APPARATUS FOR DETERMINING THE STARTING MOMENT OF ROLLING BEARINGS

A. A. Kut'kov

The measurement of the starting moments of rolling bearings is most commonly effected by the pendulum instrument shown diagramatically in Fig. 1. The instrument operates in the following way: the axle on which the bearing is mounted is set in motion with a constant low angular speed by means of an electric motor. Owing to the action of friction forces the inner race of the bearing drags the outer race and hence the retainer, pendulum and weight. The greatest angle of deflection is recorded on the scale by a pointer rigidly attached to the retainer.

This instrument is convenient for determining the starting moment but has a number of shortcomings: the scale of the instrument can be graduated only comparatively coarsely; the presence of a ponderable pendulum complicates the determination of the starting moment; the flexural deformation of the pendulum during the deflection of the load introduces certain distortions; direct observation of the instrument pointer is necessary.

Since more and more rigorous demands are being made on the quality of rolling bearings, the author, working in the Taganrog Radio Engineering Institute, has devised an improved apparatus.

An inclined plate 5 is mounted on a base 1 with adjustable feet 2. A slow and smooth variation of the inclination of the plane is effected by the rotation of a micrometer screw 9 by means of the reducing worm gear 10 driven by the axle of an electric motor 15 through electromagnetic (13) and flexible (14) couplings. For manual drive there is a pair of bevel gears 12, the driving gear being disengageable. The number of revolutions of the micrometer screw is recorded by the counter 11. The plate 5 carries a camera with lens 6 and a light source and a camera with lens 7 and photo-cell 8. Near the axis of rotation of plate 5 there is mounted a bracket 4 with a device 3 for holding the bearing under test (Fig. 3).

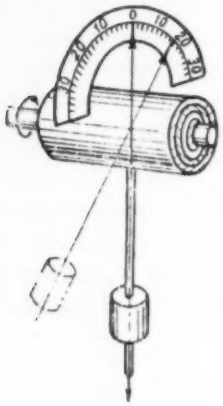


Fig. 1

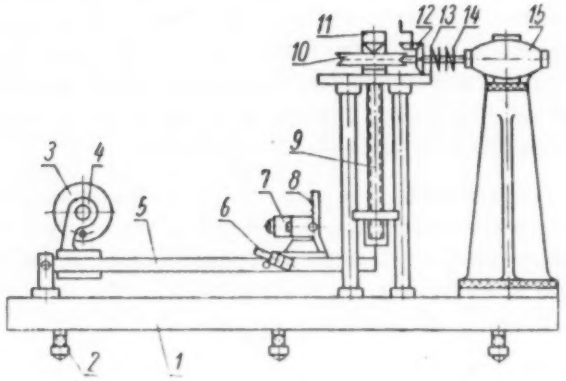


Fig. 2

The bracket (Fig. 3) carries a split bushing 16, a retainer 19 with test bearing 17 enclosed by the covers 18. The retainers are interchangeable and have constant outside dimensions and different openings for the test bearings.

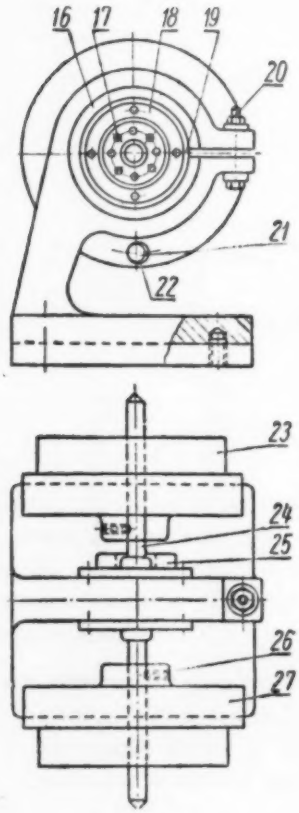


Fig. 3

The bearing is mounted on axle 24 (P_1 fitting). Double-row spherical radial bearings have axles with a longer seating for them, since these bearings are mounted on the axles in twos. By means of screws 26 steel or duralumin disks 27 are fastened to the axle. Besides these, there is a set of disks 23 (loads) of lesser diameter for changing the size of the load. Holes are bored in disks 27 at exactly the same distance from the center and through these holes is inserted a cylindrical rod 20 (sliding fit), which produces the torque.

On rod 21 a mirror 22, weight 0.5 g, is attached.

An electric heater 25 is provided for heating the lubricant.

The electrical part of the apparatus incorporates a tube amplifier, a relay, a magnetic starter, switches and indicator lamps.

In the preparation of the apparatus for the experiment the bearing under test is mounted on the axle and inserted in the retainer with it (S_1 fitting); then the covers are fitted, which is necessary in the case of testing a bearing in an oil bath or at high temperatures. The retainer with the bearing is inserted in the split bushing, which is mounted in the bracket and fastened by the screw 20 (Fig. 3).

The weights are mounted on the ends of the axle, and a rod is inserted in the holes, thus positioning the axes of the holes in one plane; the weights in turn are fixed to the axle by screws.

By manual rotation of the reducing worm-gear through the pair of bevel gears (the motor is disconnected by the electromagnetic clutch) the inclined plate 5 (Fig. 2) is set in an exactly horizontal position and checked by means of a quadrant angle gage. The position of the rod is checked by a plumb line (a weight on a fine kapron thread) by means of a vertical-motion

sighting tube. In the correct, lowest position of the rod the thread passes through the pointed ends of axle 24 (Fig. 3) and the rod. We then note the readings of the revolution counter and the graduated disk attached to screw 9 (Fig. 2).

After this the lamp of lens 6 (Fig. 2) is switched on and the position of the photocell is altered until the beam reflected by mirror 22 (Fig. 3) through the lens 7 (Fig. 2) and controlled by the size of the slit in the casing of the photocell 8 (Fig. 2) is directed on to the photocell. When a current appears in the secondary circuit the indicator lamp on the amplifier glows, thus indicating the apparatus is ready for work.

The preparation described above takes 5-7 minutes.

Experimental procedure. By pressing the starting button of the magnetic starter the electromagnetic clutch is engaged, the electric motor is switched on, and the apparatus starts to function. When the inside race of the bearing starts, the circuit is instantaneously broken, the relay of the magnetic starter is triggered at the same time, and it is automatically switched off; in the case of the return of the light beam onto the photocell in the next instant, due to the oscillation of the inside race of the bearing, the circuit of the electromagnetic clutch remains open; thus the counter and dial stop the moment the inner race of the bearing starts to move.

A diagram of the action of the apparatus is shown in Fig. 4, where L is the designed length of the inclined plane, L_1 is the distance from mirror to photocell, h is the rise of the plane for one revolution of the screw, φ is the angle of inclination of the plane, α is the conditional angle of deflection of the rod, β is the true angle of deflection of the rod, γ is the angle of lag of the rod, R is the distance from the center of the axle to the center of the bar, D is the diameter of the light beam passing through the slit, ΔA is the height of the slit in the photocell casing.

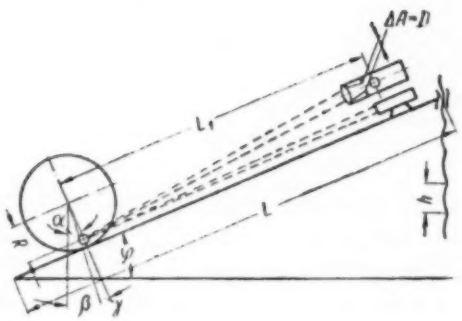


Fig. 4

As was found in the experiments, the inner race of the bearing under the action of the starting moment created by the weight of rod Q at radius R, will lag behind the outer when it rotates through a certain angle before the starting moment. The greatest value of the angle γ for bearing 204 lubricated by consistent lubricant NK-50 was equal to 4'. At the same time the angle of inclination of the plane φ was equal to 3°. Hence, the greatest value of angle γ is 2.2% of the angle φ, and therefore its value can be neglected, so that $\beta = \alpha = \varphi$. In this case the starting moment is determined from the formula

$$M = QR \sin\alpha. \qquad (1)$$

Since Q = 100 g, R = 50 mm, L = 500 mm, h = 1 mm, with rise angles φ of the inclined plate up to 4°20' (i.e., up to 38 g·cm), sin α and tan φ will be practically equal, and hence the starting moment will change by 1 g·cm on one full turn of the screw. Hence, the counter registers the value of the starting moment in grams per centimeter, and since the graduated disk is divided into 200 parts the starting moment is determined with an error of 0.005 g·cm. When the angle of rotation φ is more than 4°20', i.e., when the turning moment is more than 38 g·cm (this rarely occurs, only with viscous lubricants and at low temperature) a correction table compiled beforehand must be used. In this case to the starting moment obtained from the counter we must add the value corresponding to the lag of the difference of the sine and tangent of the angle. Yet this difference is very small: for instance, at the maximum height of the screw, equal to 100 mm (100 turns of the screw), tan $\varphi = 0.2$ and $\varphi = 11°20'$, while sin $11°20' = 0.197$.

The apparatus operates when the inner race of the bearing moves through an angle δ relative to the outer:

$$\delta° = \frac{\Delta A}{2L_1} \cdot \frac{180}{\pi} \simeq 0.1636° = 9'.816.$$

In this case the inner race of bearing 204 travels through an arc equal to approximately 0.03 mm. The rotational speed of the screw and disk is 6 to 20 rpm.

SUMMARY

The described apparatus for measuring the starting moment of rolling bearings is distinguished by its automatic operation, which excludes the human errors which may occur in the direct reading of an instrument scale, the absence of a ponderable pendulum, the great stability of the readings, the exclusion of friction effects of any other mechanical systems, high sensitivity, which makes it possible to record moments differing by 0.005 g·cm, smooth and continuous increase of the external torque, the possibility of installing the apparatus in an airtight chamber in which the atmosphere can be varied (vacuum, various gases, increased pressure, etc.), and thus it possesses significant advantages over other known instruments.

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CONVEYOR FOR TESTING VPG-500 (M) BALANCES

G. N. Pronin and B. G. Kirillov

An all-metallic testing conveyor, of width 1 m and working length 16 m, was designed, built and installed at the "Krasnolit" factory to increase the output of platform-type moving-weight balances with maximum load 500 kg.

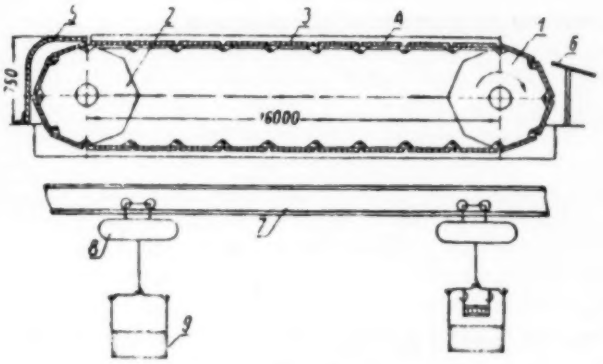

Fig. 1

The conveyor (Fig. 1) consisted of an octagonal driving drum, 1, a tension drum, 2, and an articulated metal plate belt, 3, sliding in a horizontal directing guide, 4. At the tension drum end was a protective casing, 5, and at the driving drum end was a take-off device, 6, for unloading the balances which had been tested and approved. The driving drum was rotated, through a reducing gear, by a 2.8 kw motor. The belt speed was 0.4 m/minute.

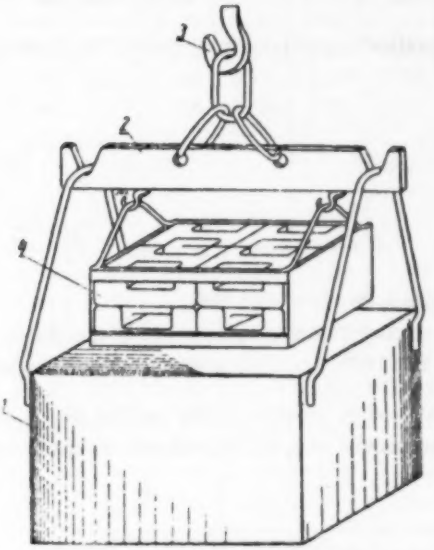

Fig. 2. 1) Standard 3rd class weight of mass 500 kg; 2) beam suspension; 3) hook of electric telpher cable; 4) supplementary weight for testing balance at 125% of limiting load.

In order to determine the error in the balance readings at limiting load, underneath the conveyor and parallel to its longitudinal axis was a railway, 7, on which moved two electric telphers, 8, with standard 500 kg weights, 9.

The standard weights were suspended from the telphers (Fig. 2) in a way that ensured automatic freeing of the weight on raising of the balance platform and its subsequent reengagement on lowering of the cable.

Before the conveyor was introduced, the balances were tested on a 600 m^2 table, and it required 10 testers and 7 assistants to adjust the balances and move the 3rd class standard 20 kg weights. The maximum output was 110 balances per shift.

Experience with testing on the conveyor showed that, with the same number of testers and 3 assistants, it was possible to maintain an output of 180 balances per shift, and that conditions were provided for smooth running of the workshop.

Introduction of the conveyor freed about 600 m^2 of working space, reduced the number of workers in the section, mechanized the manual labor of testing, increased productivity by 65% and saved more than 200,000 rubles in the course of a year.

SIMPLIFIED METHOD OF CALIBRATING SPHEROVALOIDAL DISHED ENDS

N. V. Nikolin

The existing method of determining the theoretical volume of a spherovaloidal dished end (a spherical end with two radii of curvature) by calculation based on trigonometry is complicated for practical workers and very laborious, so that it is not widely used for calibrating static tanks.

Simplified formulas may be used for determining the volumes of spherovaloidal dished ends:

$$V_d = \frac{\pi D_d^2}{4} f_d \psi,$$

$$V_d = \frac{\pi}{8}[D_d - r_0]^2 \cdot [f_d + r_0].$$

where f_d is the depth of the dish,

ψ is a coefficient characterizing the shape of the dish,

r_0 is the radius of the curve joining the spherical and ovaloid parts of the dish.

But the use of these requires careful and tedious measurement of the precise radius r_0; any lack of precision in the measurement of r_0 can produce a considerable error in the determination of the volume.

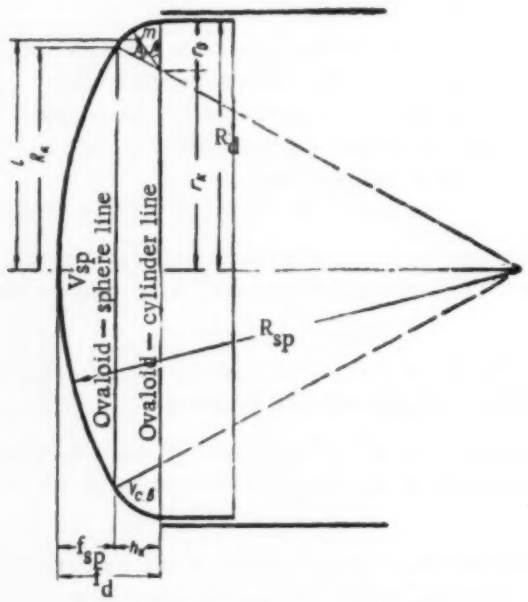

Fig. 1. Diagram of existing method of calculation for spherovaloidal dish.

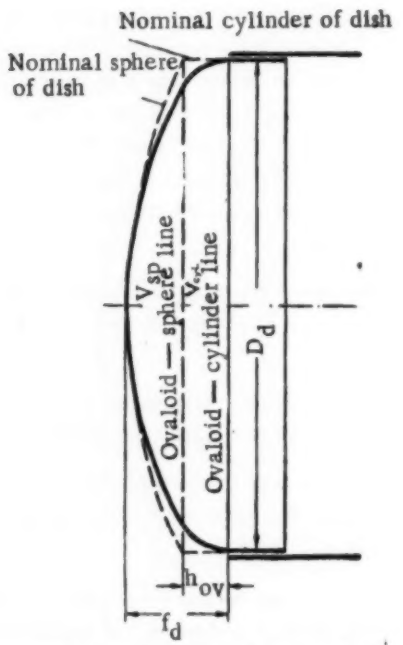

Fig. 2. Diagram of simplified method of calculation for spherovaloidal dish.

Another drawback to the use of these formulas is that they are only suitable for determining the volumes of the dished ends of iron cisterns and static tanks where the junction between the spherical and ovaloid parts has a small radius of curvature ($r_0 : D_d \nmid 0.08$), and cannot be applied to standard tanks used in our industry for many years in accordance with GOST 793-44 (e.g., tanks GRS-13 and GRS-24), or to static tanks with dished ends such that the junction has a large radius of curvature.

TABLE 1

Depth of dish f_d, mm	Values of the coefficients K_1, K_2, and K_3, as functions of the base diameter of the dish and the dish depth														
	D=1695 mm			D=1700 mm			D=1705 mm			D=1710 mm			D=1715 mm		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
330	0.479	0.959	0.858	0.477	0.961	0.863	0.475	0.963	0.867	0.473	0.966	0.873	0.471	0.969	0.880
335	0.494	0.950	0.824	0.493	0.952	0.827	0.492	0.953	0.829	0.490	0.954	0.836	0.488	0.955	0.843
340	0.506	0.941	0.797	0.506	0.943	0.799	0.505	0.944	0.801	0.504	0.945	0.804	0.502	0.947	0.808
345	0.519	0.936	0.765	0.516	0.937	0.770	0.514	0.937	0.774	0.513	0.937	0.777	0.512	0.937	0.780
350	0.526	0.927	0.745	0.525	0.928	0.747	0.524	0.928	0.748	0.523	0.930	0.752	0.522	0.932	0.756
	D=2190 mm			D=2195 mm			D=2200 mm			D=2205 mm			D=2210 mm		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
480	0.527	0.920	0.724	0.526	0.922	0.727	0.526	0.923	0.729	0.525	0.923	0.731	0.523	0.923	0.733
485	0.534	0.915	0.701	0.533	0.916	0.703	0.532	0.917	0.706	0.532	0.918	0.709	0.531	0.919	0.713
490	0.540	0.907	0.679	0.539	0.909	0.684	0.538	0.911	0.688	0.538	0.912	0.689	0.537	0.914	0.691
495	0.547	0.902	0.658	0.546	0.904	0.660	0.546	0.905	0.662	0.545	0.906	0.666	0.543	0.907	0.672
500	0.550	0.895	0.639	0.550	0.898	0.642	0.550	0.901	0.645	0.549	0.902	0.647	0.548	0.903	0.649
	D=2390 mm			D=2395 mm			D=2400 mm			D=2405 mm			D=2410 mm		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
530	0.525	0.920	0.725	0.524	0.920	0.728	0.523	0.921	0.731	0.522	0.921	0.734	0.520	0.922	0.738
535	0.532	0.915	0.704	0.530	0.917	0.708	0.529	0.918	0.711	0.529	0.919	0.713	0.529	0.920	0.715
540	0.538	0.911	0.683	0.537	0.912	0.687	0.536	0.913	0.690	0.536	0.913	0.693	0.535	0.913	0.696
545	0.544	0.906	0.664	0.544	0.908	0.666	0.544	0.910	0.668	0.542	0.911	0.672	0.540	0.911	0.677
550	0.547	0.900	0.645	0.546	0.901	0.648	0.546	0.902	0.651	0.546	0.902	0.654	0.545	0.903	0.657
	D=2590 mm			D=2595 mm			D=2600 mm			D=2605 mm			D=2610 mm		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
510	0.491	0.953	0 834	0.490	0.954	0.837	0.489	0.955	0.840	0.488	0.955	0.843	0.486	0.955	0.846
515	0.498	0.946	0.805	0.498	0.947	0.812	0.498	0.948	0.819	0.497	0.948	0.821	0.495	0.949	0.824
520	0.507	0.942	0.794	0.506	0.943	0.798	0.506	0.944	0.802	0.505	0.945	0.803	0.503	0.947	0.804
525	0.514	0.935	0.775	0.513	0.936	0.778	0.513	0.937	0.780	0.512	0.938	0.782	0.511	0.939	0.785
530	0.521	0.930	0.755	0.519	0.930	0.756	0.518	0.931	0.756	0.517	0.932	0.761	0.517	0.933	0.767

In order to facilitate measurement of the dish in practice and to reduce the subsequent calculation required to determine the total volume of the dish and the volumes of its parts (spherical segment and ovaloid), we avoid the specially difficult determination of r_0 and ψ (Figs. 1 and 2). The ovaloid part of the dish is provisionally treated as a cylinder, of diameter equal to the internal diameter of the base of the dish, and of height equal to that of the ovaloid part of the dish. The spherical part of the dish is provisionally treated as a spherical segment, with a base diameter equal to that of the base of the dish, D_d, and a height, f_{sp}, equal to the total depth of the dish, f_d, minus the height of the ovaloid part of the dish, h_{ov}.

The volumes derived for the whole dish and for the ovaloid and spherical parts, on the basis of this simplified approximation to the true shape, will be somewhat too high, but the necessary precision in obtaining the true volumes of the whole and of the parts of the dish can be obtained by applying correction coefficients to the new simplified formulas.

TABLE 2

Depth of dish f_d, mm	Values of coefficients for determining the height h_{ov}, of the ovaloid part of the dish as a function of the base diameter of the dish and the dish depth, f_d				
	D=1695 mm	D=1700 mm	D=1705 mm	D=1710 mm	D=1715 mm
330	0.330	0.322	0.315	0.303	0.291
335	0.397	0.386	0.385	0.373	0.370
340	0.444	0.442	0.441	0.430	0.427
345	0.496	0.488	0.481	0.477	0.472
350	0.531	0.527	0.523	0.517	0.511
	D=2190 mm	D=2195 mm	D=2200 mm	D=2205 mm	D=2210 mm
480	0.548	0.545	0.542	0.538	0.533
485	0.579	0.575	0.571	0.567	0.563
490	0.608	0.603	0.598	0.595	0.592
495	0.636	0.632	0.628	0.623	0.618
500	0.656	0.652	0.648	0.645	0.642
	D=2390 mm	D=2395 mm	D=2400 mm	D=2405 mm	D=2410 mm
530	0.543	0.538	0.534	0.530	0.526
535	0.572	0.565	0.559	0.558	0.557
540	0.598	0.594	0.591	0.588	0.585
545	0.622	0.619	0.617	0.613	0.609
550	0.644	0.641	0.638	0.636	0.633
	D=2590 mm	D=2595 mm	D=2600 mm	D=2605 mm	D=2610 mm
510	0.378	0.373	0.369	0.365	0.361
515	0.419	0.413	0.408	0.403	0.398
520	0.448	0.444	0.440	0.436	0.431
525	0.480	0.477	0.474	0.470	0.465
530	0.511	0.506	0.502	0.498	0.494

We have introduced the following simplified formulas for obtaining the total volume of the spherovaloidal dished end and the volumes of its separate parts:

1) the total volume of the spherovaloidal dish

$$V_d = K_1 f_d D_d^2$$

2) the volume of the ovaloid part

$$V_{ov} = K_2 \frac{\pi D^2}{4} h_{ov}$$

3) the volume of the spherical part

$$V_{sp} = K_3 \cdot 0.4 f_{sp} D^2,$$

where K_1 is the ratio of the theoretically calculated to the provisional volume of the dish,

K_2 is the ratio of the theoretically calculated volume to the provisional volume as a cylinder of the ovaloid part of the dish,

K_3 is the ratio of the theoretically calculated to the provisional volume of the spherical part of the dish,

h_{ov} is the actual height of the ovaloid part of the dish,

f_{sp} is the actual height of the spherical part of the dish ($f_{sp} = f_d - f_{ov}$),

D_d is the actual internal diameter of the base of the dish.

Our calculated values of the above coefficients for standard tanks according to GOST 793-44, which have been manufactured for several years, with allowances for possible variations in diameter and depth of dish of ± 13 mm, are shown in Tables 1 and 2.

TABLE 3

Value of ratio $\frac{h_{ov}}{f_d}$	Values of coefficients	
	K_1	K_2
До 0.200	0.445	0.990
0.201—0.225	0.455	0.985
0.226—0.250	0.465	0.980
0.251—0.275	0.470	0.975
0.276—0.300	0.480	0.970
0.301—0.325	0.480	0.965
0.326—0.350	0.485	0.960
0.351—0.375	0.490	0.955
0.376—0.400	0.495	0.950
0.401—0.425	0.500	0.950
0.426—0.450	0.505	0.945
0.451—0.475	0.510	0.940
0.476—0.500	0.515	0.935
0.501—0.525	0.520	0.930
0.526—0.550	0.525	0.925
0.551—0.575	0.530	0.920
0.576—0.600	0.535	0.915
0.601—0.625	0.540	0.910
0.626—0.650	0.545	0.900
0.651—0.675	0.550	0.895

If the diameter or depth of dish does not coincide with a value given in Table 1, then the coefficient can either be taken from the nearest value or by interpolation. Any differences between the volumes obtained in this way and by theoretical calculation (a maximum of 10 to 15 liters) can be neglected in practice.

In the case of larger differences between the dimensions of a tank and the GOST specification, i.e., with nonstandard tanks, it is sufficient to determine the actual values of the depth of the dished end, f_d, the height of the ovaloid part of this, h_{ov}, and the diameter of the base of the dish, D_d.

The following rule has been found from an analysis of the dimensions of a large number of standard and spherovaloidal dished ends: with an increase in the ratio of the height of the ovaloid part of the dish, h_{ov}, to the total depth of the dish, f_d, the ratio K_1 of the theoretically calculated to the provisional volume increases, but the ratios K_2 of the theoretically calculated volume of the ovaloid part to its provisional volume as a cylinder, and K_3, of the theoretically calculated to the provisional volume of the spherical part, decrease.

The approximate values of K_1 and K_2, given in Table 3, can be used to determine the volumes of spherovaloidal dished ends of nonstandard tanks.

Any differences between the volumes obtained using Table 3 and theoretically calculated volumes can be neglected in practice.

This simplified method we have introduced, for finding the total volumes or the volumes of the parts of dished ends, does not involve measurement of the radius of curvature of the junction, r_0, which is difficult in practice, nor subsequent determination of the coefficient, ψ, from a special graph, and yet is applicable to dished ends of all dimensions, so that it is within the capacity of all practical workers.

With tanks of the standard type, where the depth and diameter of the dish are within ± 13 mm of the specified value, the height of the ovaloid part can be taken from Table 2.

With nonstandard tanks, the height of the ovaloid part of the dish can be determined with a rule and a plumb line whose cord is attached to the lower part of the dished end at a point of transition from ovaloid to sphere. The height of the ovaloid part is then measured with the rule, one end of which is held against the cylindrical part of the dish, while the other end is held in a horizontal position with the other hand.

The line of transition between the ovaloid and spherical parts of the dished end is usually obvious in practice, and any difference between the observed and theoretically calculated values of the height of the ovaloid part should not exceed ± 5 mm. The difference between the corresponding values obtained for the volume of the dished end will then be inconsiderable, since the depth of the dished end is measured precisely in practice.

For subsequent point-by-point calibration of the dished ends in question, for each centimeter of height of filling, T. S. Alekseev recommends use of the formula

$$V_{vel} = V_d K_d$$

where V_{vel} is the volume of the dished end up to a given height of filling,

V_d is the total volume of the dished end,

K_d is the calibration coefficient for the spherovaloidal dished end for the given height of filling of the latter.

The value of the coefficient K_d can be determined from the formula

$$K_d = \frac{(1-\psi) K_{sp}}{\psi} + \frac{(2\psi-1) K_{cyl}}{\psi}$$

or, for values of $\psi = 0.57$, 0.59, 0.62, and 0.66, can be obtained directly from "Tables for the Calibration of Iron Cisterns;" both these methods of finding K are applicable to iron cisterns and static tanks with a small depth of dished end, i.e., when $r_0 : D_d \nmid 0.08$. This formula and the tabulated values of K_d are not applicable to tanks of the standard type and static tanks, as the result of which restriction (which includes the Glavneftesbyt methods) it is necessary to calibrate spherovaloidal dished ends by the method for normal spherical dished ends, or by the combined equivalent method, judging "by eye" the place of intersection of the nominally extended spherical dish with the extended cylindrical part of the dished end. It is very difficult in practice to determine this place with precision, since the sphere is not a plane, and a ruler placed on it may take up different positions and will not give a true indication of the position of its intersection with another ruler, placed along the cylindrical part of the dished end of the tank.

Two new methods are proposed to simplify the point-by-point calibration of a spherovaloidal dished end:

1) the method of separate calibration of the spherovaloidal dished end (with provisional separation of the dish into a spherical segement and a cylinder, and subsequent application of correction coefficients);

2) calibration of the spherovaloidal dish by the normal method for spherical dished ends (less accurate).

In the method of separate calibration, standard calibration methods are applied to the nominal spherical and cylindrical parts of the dish. Determination of the volumes of these parts is carried out as above. In the point-by-point calibration of the tank as a whole, i.e., including its cylindrical part, in order to speed up calculations, the volumes of the nominally cylindrical parts of the two dished ends are combined with the volume of the cylindrical part of the tank, and this combined volume is taken as the calculated volume for the whole of the cylindrical part of the tank. It is then only necessary to consider the volumes of the spherical parts of the dished ends.

This method of point-by-point calibration of spherovaloidal dished ends, particularly when applied to standard tanks, is simple enough, applicable to dished ends of all dimensions, is sufficiently precise, does not require preliminary determination of the radius of curvature of the junction between the spherical and ovaloidal parts of the end, does not need a special graph for finding the value of the coefficient ψ, characterizing the shape of the dish, and is therefore the most practicable.

In point-by-point calibration by the spherical dish method, the spherovaloidal dished end is taken as nominally equivalent in volume to a spherical dish. The depth of the nominally spherical dish must be calculated from the formula

$$f_{sp} = \frac{V_d}{0.4 D_d^2}$$

where V_d is the volume of the dish, actual or calculated from the accepted formula,

D_d is the internal diameter of the base of the dish.

The whole subsequent calibration of the dished end, through each centimeter of height of filling of the tank, is then carried out by the standard method of calibrating spherical dished ends; this method is convenient in that it is well known and quite simple, but it is only applicable when the ratio $f_{nom} : D_d$ does not exceed 0.2.

Example 1. The dished end of a standard tank, type GRS-51, has the following internal dimensions: base diameter 2595 mm, depth of dish, f_d, 515 mm. It is required to find the volume of the dish by the separation method.

For standard tanks, where the deviations from the standard dimensions do not exceed ± 13 mm, the values of K_1 can be taken from Table 1.

$$K_1 = 0.498. \quad V_d = K_1 f_d D^2 = 0.498 \times 0.515 \times 2.595^2 = 1.727 \text{ m}^3.$$

Example 2. The dished end of a nonstandard tank has the following internal dimensions: base diameter of dish 2580 mm, depth of dish, f_d, 315 mm, height of ovaloidal part of dish, h_{ov}, 96 mm. It is required to find the volume of the dish.

The ratio $\frac{h_{ov}}{f_d} = \frac{96}{315} = 0.305$. From Table 3 this value of the ratio corresponds to $K_1 = 0.480$. The volume of the dished end is given by $V_d = K_1 f_d D^2 = 0.480 \times 0.315 \times 6.6564 = 1.006 \text{ m}^3$.

Example 3. The volume of a spherovaloidal dished end is 0.981 m^3 and the diameter of the base of the dish is 2578 mm. It is required to carry out a point-by-point calibration of the dished end by the method of calibrating spherical dishes.

$$f_{nom} = \frac{V_d}{0.4 D_d^2} = \frac{0.981}{0.4 \times 2.578^2} = 0.369 \text{ m} = 369 \text{ mm}.$$

The ratio $\frac{f_{nom}}{D_d} = \frac{369}{2578} = 0.143$. The whole of the subsequent calibration of the dished end in question is carried out by the method of calibrating spherical dishes.

Example 4. The dished end of a standard tank has the following internal dimensions: $D_d = 2602$ mm, depth of dish = 513 mm.

In using Table 1, we take a dish of the nearest dimensions to those of the given dish, $D_d = 2600$ mm, and $f_d = 515$ mm, and read off $K_2 = 0.948$ and $K_3 = 0.819$. From Table 2, the height, h_{ov}, of the ovaloidal part of the dish will be $0.408 f_d$. The depth of the spherical part of the dish will be equal to the depth of the whole dish minus the depth of the ovaloid part, i.e., $f_{sp} = f_d - f_{ov} = 0.592 f_d$; $V_{ov} = K_2 \frac{\pi D^2}{4} h_{ov} = 0.948 \times$ $\times 5.31746 \times 0.408 \times 0.513 = 1.056 \text{ m}^3$; $V_{sp} = V_d - V_{ov}$, or $V_{sp} = K_3 (0.4) f_{sp} D^2 = 0.819 \times 0.4 \times 0.592 \times$ $\times 0.513 \times 2.602^2 = 0.674 \text{ m}^3$.

Subsequent point-by-point calibration of these parts of the dished ends is carried out in conformity with the methods for calibrating a cylinder and a spherical segment.

Example 5. The dished end of a nonstandard tank has the following internal dimensions: $D_d = 2578$ mm, $f_d = 314$ mm, $h_{ov} = 94$ mm. It is required to carry out a point-by-point calibration of the dished end by the separation method.

From Table 3, for $\frac{h_{ov}}{f_d} = 0.300$, $K_1 = 0.480$ and $K_2 = 0.970$. The total volume of the dish is $V_d = K_1 f_d D^2 =$ $= 0.480 \times 0.314 \times 2.578^2 = 1.002 \text{ m}^3$.

The volume of the ovaloid part of the dish is $V_{ov} = K_2 \frac{\pi D^2}{4} h_{ov} = 0.970 \times 5.2198 \times 0.094 = 0.476\ m^3$.

The volume of the spherical part of the dish is $V_{sp} = V_d - V_{ov} = 1.002 - 0.476 = 0.526\ m^3$.

Subsequent point-by-point calibration of these parts of the dished ends is carried out in conformity with the methods for calibrating a cylinder and a spherical segment.

THE PROBLEM OF DETERMINING THE CAPACITIES OF CYLINDRICAL TANKS FOR OIL PRODUCTS*

V. F. Dubenskov

To speed up and simplify calculation of the capacities of cylindrical tanks, with plane and with spherical and conical dished ends, and also to construct centimeter calibration tables, it is proposed that computation tables for diameters of 50 to 325 cm should be produced of the type given in [1], but that, instead of the columns for $\frac{H}{D}$ and K_z, there should be columns for $K_{cyl} V_{cyl}$, $K_{sph} V_{sph.d}$ and $K_{con} V_{con.d}$, for ratios of depth of dish to diameter of $\frac{1}{5}$ to $\frac{1}{30}$ (for pattern see Table 1).

TABLE 1

Height of filling, cm	Capacity of 1 cm length of cylindrical part, liters	Ratio of depth of spherical or height of conical end to diameter of tank, D											
		1/30 (0,033)		1/20 (0,050)		1/15 (0,067)		1/10 (0,100)		1/8 (0,125)		1/5 (0,200)	
		Capacity of dished end, liters											
		S	C	S	C	S	C	S	C	S	C	S	C
1	2	3	4	5	6	7	8	9	10	11	12	13	14

Each table contains 14 columns. Column 1 is the height of filling of the oil product in the tank; column 2 gives the corresponding capacity for 1 cm length of the cylindrical part of the tank (in liters); columns 3,5, 7, 9, 11, and 13 (S) give the corresponding capacities of the spherical end, as adopted in Methodical Instructions No. 149 of the Committee of Standards, Measurements and Measuring Equipment, for ratios of $\frac{f}{D}$; columns 2, 4, 6, 8, 10, 12, and 14 (C) give the corresponding capacities of the conical end for the same ratios of cone height to diameter as are shown in the table for ratio of depth of spherical end to diameter.

By means of such tables, with tanks whose diameter and length correspond to the tabular values or differ little from them, a calibration table can be produced rapidly and accurately for a tank whose shape, diameter and depth of spherical,or height of conical,end are equal to the tabular values, and the capacity of the tank can be found for any height of filling.

The capacity of a tank up to any given level is calculated from the table in parts; first the capacity of the cylindrical part is found and then the capacity of the two dished ends up to the same level.

* In course of consideration.

To determine the capacity of the cylindrical part of the tank, it is only necessary to multiply the capacity given in column 2 for 1 cm length, corresponding to the given level, by the effective (internal) length of the cylindrical part, expressed in centimeters.

The capacity of the conical or spherical dished end, of depth equal to a tabulated value, can be obtained for any level from the corresponding column of Table 1.

For tanks such that the diameter and depth of spherical, or height of conical, dished end do not conform with the tabular values, the point-by-point volumes can be found by interpolation.

For tanks having two different-sized spherical or conical dished ends, the volume of oil product is calculated for each end separately.

These tables can also be used to find the point-by-point capacities of tanks with a truly elliptical section and plane ends.

To do this we find the capacity up to the same level of a horizontal cylindrical tank, whose diameter is equal to that of a circle inscribed in the ellipse: $D = 2b$, where D is the diameter of the cylindrical tank and b is the minor semi-axis of the ellipse. The capacity found is then multiplied by $\frac{a}{b} L$, where a and b are the semi-axes of the ellipse and L is the effective length of the tank (in cm).

The proposed method of determining the capacity of an elliptical horizontal tank requires the development of a method of checking the true ellipticity of a section, which will make it possible to allow for any deviation of the actual cross section from that of a true ellipse, and to establish a permissible error of measurement for the tank.

TABLE 2

Height of filling, cm	Capacity of 1 cm length of cylindrical part, liters	Depth of dished end, mm											
		33 (1/30)		50 (1/20)		67 (1/15)		100 (1/10)		125 (1/8)		200 (1/5)	
		Capacity of dished end, liters											
		S	C	S	C	S	C	S	C	S	C	S	C
1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.037	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0.069	0.013	0.009	0.020	0.013	0.026	0.018	0.040	0.026	0.050	0.033	0.083	0.052
64	5.308	9.448	6.463	14.312	9.791	19.270	13.120	28.957	19.583	36.430	24.478	59.896	39.165
65	5.404	9.643	6.592	14.637	9.988	19.667	13.383	29.548	19.975	37.182	24.969	61.137	39.951
66	5.499	9.837	6.722	14.933	10.184	20.038	13.646	30.125	20.368	37.883	25.460	62.378	40.736
74	6.231	11.187	7.595	16.981	11.506	22.817	15.418	33.872	23.012	43.145	28.765	70.982	46.024
75	6.318	11.330	7.690	17.198	11.650	23.108	15.611	34.341	23.300	43.696	29.125	71.892	46.600
76	6.404	11.472	7.776	17.415	11.781	23.373	15.786	34.699	23.562	44.197	29.452	72.802	47.124
84	7.043	12.381	8.312	18.794	12.533	25.226	16.873	37.925	25.185	47.755	31.481	78.676	50.370
85	7.115	12.459	8.355	18.912	12.658	25.411	16.961	38.173	25.316	48.055	31.645	79.255	50.632
86	7.186	12.537	8.398	19.030	12.721	25.544	17.049	38.312	25.447	48.356	31.809	79.752	50.896
98	7.817	12.978	8.640	19.700	13.090	26.470	17.540	39.793	26.180	50.110	32.725	82.730	52.360
99	7.841	12.978	8.640	19.700	13.090	26.470	17.540	39.795	26.180	50.110	32.725	82.730	52.360
100	7.854	12.978	8.640	19.700	13.090	26.470	17.540	39.796	26.180	50.110	32.725	82.730	52.360

Below are given some examples of calculations of the capacities of tanks with conical and spherical ends.

a) Diameter of tank equal to tabular value.

Example 1. A tank with spherical ends has the dimensions $D_{int} = 100$ cm, $L_{cyl} = 240$ cm and $f_{sph.d} = 100$ mm, and it is required to find the volume of oil when the depth of filling is $H = 65$ cm.

From Table 2 we find the volume for 1 cm length of the cylindrical part of the tank when $H = 65$ cm. The value found (5.404 liters) is multiplied by the effective length of the tank expressed in centimeters to give the volume of oil up to the given level in the cylindrical part of the tank:

$$V_{cyl} = 5.404 \times 240 = 1297 \text{ liters.}$$

In column 9 of Table 2 we find the capacity of one spherical end, with $f_{sph \cdot d} = 100$ mm, up to H = 65 cm, to be 29.548 liters. By combining the volume of the cylindrical part of the tank with the volumes of two spherical ends, we obtain the required volume of oil in the tank up to the level H = 65 cm:

$$V = 1297 + (29.548 + 29.548) = 1356 \text{ liters.}$$

Example 2. A tank with conical ends has the dimensions $D_{int} = 100$ cm, $L_{cyl} = 240$ cm, and $f_{con \cdot d} = 100$ mm, and it is required to find the volume of oil when the depth of filling is H = 75 cm.

From Table 2 we find the volume for 1 cm length of the cylindrical part when H = 75 cm. The value found, 6.318 liters, is multiplied by the effective length of the cylindrical part of the tank, expressed in centimeters, to give the volume of oil up to the given level in the cylindrical part of the tank:

$$V_{cyl} = 6.318 \times 240 = 1516.3 \text{ liters.}$$

In column 10 of Table 2 we find the capacity of one conical end, with $f_{con \cdot d} = 100$ mm, up to H = 75 cm, to be 23.300 liters. By combining the capacities of the cylindrical part of the tank and the capacities of two conical ends, up to H = 75 cm, we find the required volume of oil in the tank up to the level given:

$$V = 1516.3 + (23.300 + 23,300) \sim 1563 \text{ liters.}$$

b) Diameter of tank not equal to a tabular value.

Corrections, calculated from the difference in diameters, are applied to the tabulated values of the point-by-point capacities of the cylindrical part (column 2) and dished end (columns 3-14).

The corrections are applied by multiplying the tabulated capacity of 1 cm length of the cylindrical part by D^2 and that of the dished end by D^3, where D is the diameter of the tank being measured (in m).

When first looking up the capacities in Table 2, we use the level in a D = 100 cm tank which gives the same ratio of $\frac{H}{D}$, find the capacities of the cylindrical part and dished ends by applying the corrections, and combine these to obtain the required capacity of the tank being measured.

Example 3. A tank with conical ends has the dimensions D = 200 cm, $L_{cyl} = 400$ cm and $f_{con \cdot d} = 250$ mm, and it is required to find the volume of oil when H = 151 cm.

In Table 2 this height corresponds to a height of filling

$$h = \frac{H}{D} = \frac{151}{200} = 75.5 \text{ cm.}$$

The capacity of 1 cm length of the cylindrical part corresponding to this height is not in Table 2, and must therefore be found by interpolation. In Table 2, a height of 76 cm corresponds to 6.404 liters, and a height of 75 cm corresponds to 6.318 liters. The capacity of 1 cm length of the cylindrical part of a tank of D = 100 cm and h = 75.5 cm will therefore be:

$$V_{cyl} = 6.318 + 0.043 = 6.361 \text{ liters.}$$

The capacity of 1 cm length of the cylindrical part of a tank of D = 200 cm and H = 151 cm will therefore be:

$$V_{cyl} = 6.361\ D^2 = 6.361 \times 4 = 25.444 \text{ liters.}$$

The total volume of the cylindrical part of the tank up to H = 151 cm will therefore be:

$$V_{cyl} = 25.44 \times 450 = 11449.8 \text{ liters.}$$

From column 14 of Table 2 we find the capacity of a single conical end, of $f_{con.d} = 250$ mm, to be 46.6 liters at h = 75 cm and 47.124 liters at h = 76 cm; by interpolation the capacity of the end at h = 75.5 cm is found to be 46.862 liters.

The capacity of an equivalent dished end, for a tank of D = 200 cm, $f_{con.d} = 250$ mm and H = 151 cm, will therefore be:

$$V_{con.d} = 46.862\, D^3 = 46.862 \times 8 = 374.896 \text{ liters.}$$

The required total volume of oil in the tank up to the given level is therefore:

$$V = 11{,}449.8 + (374.896 + 374.896) = 12{,}199.6 \text{ liters.}$$

c) Depth or height of dished end not corresponding to tabular value.

Example 4. A tank with spherical dished ends has the dimensions $D_{int} = 100$ cm, $L_{cyl} = 240$ cm, and $f_{sph.d} = 75$ mm, and it is required to find the volume of oil when H = 85 cm.

The volume of oil in the cylindrical part of the tank, when H = 85 cm, will be:

$$V_{cyl} = 7.115 \times 240 = 1707.6 \text{ liters.}$$

The volume of oil in the spherical end, up to the same height of filling, is found by interpolation. From column 7 of Table 2 we find the volume of a spherical end, up to H = 85 cm, for the nearest value of $f_{con.d}$, namely 67 mm. This volume, 25.411 liters, can be used to find the volume of a spherical end for which $f_{con.d} = 75$ mm:

$$V_{sph.d} = \frac{25.411 \times 75}{67} = 28.445 \text{ liters.}$$

Adding the volume of the cylindrical part of the tank to the volumes of two spherical ends, for the same value of H = 85 cm, we find the required volume of oil in the tank up to the given level:

$$V = 1707.6 + (28.445 + 28.445) = 1764.5 \text{ liters.}$$

LITERATURE CITED

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NEW EQUIPMENT FOR CHECKING HEAT-POWER INSTRUMENTS

A. N. Gordov, A. M. Brodskii, M. S. Kalander, and A. L. Skragan

The description is given below of special equipment for testing heat-power instruments which permits a considerable increase in the efficiency of testing and does not require highly qualified operators, developed by the D. I. Mendeleev All-Union Scientific Research Institute of Metrology. The main property of both devices is the simplicity of testing and the ease in connecting the tested objects to the measuring circuit.

The UTT-1 apparatus for testing thermocouples and resistance thermometers is designated for measuring the electrical quantities in checking temperature data transmitters of thermocouples and resistance thermometers. It provides for the possibility of simultaneously connecting eight tested thermocouples and three resistance thermometers, which are connected one by one to the measuring circuit of the apparatus by means of a built-in switch.

As to construction, the apparatus is made in the form of a metallic working-table with a built-in standard semi-automatic potentiometer, standard cell, standard resistance coils, galvanometer, switching devices, regulating resistance box, and other parts.

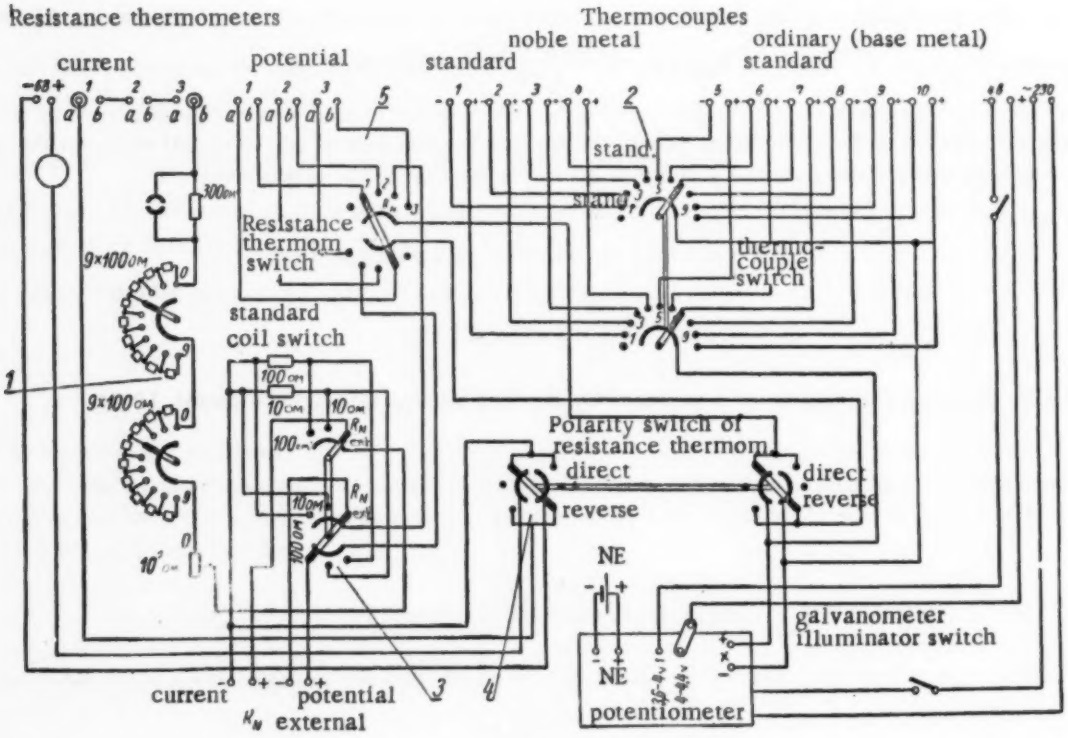

Fig. 1

Figure 1 shows the schematic diagram of the apparatus, having two independent basic circuits which serve for the measurement of the resistance of thermometers and the emf of thermocouples by the compensation method.

The intensity of current flowing through the thermometers can be regulated within 4 to 10 ma by the resistance box 1 . If it is desirable to perform measurements with weaker currents, it is possible to connect an additional box in the circuit.

The standard resistances of 10 or 100 ohm which are available in the apparatus can be alternately connected in series with the thermometers in the circuit of the apparatus by means of a special switch 3. When this switch is in position R_N, it is possible to connect a coil of any other rating or a standard four-terminal thermometer, for which terminals designated by "R_N outside" are provided, on the front panel of the apparatus.

In order to reduce measurement errors caused by parasitic thermo emf's, a special polarity switch 4 is provided in the apparatus and the contacts of the corresponding switches of the apparatus are placed in thermal equilibration chambers.

The voltage conductors from resistance thermometers and from the standard coil are connected through the thermometer switch 5 and the polarity switch to the terminals X of the potentiometer. Thus, the change of polarity in the circuit is performed simultaneously and in coordination with the change of terminals in the potential measuring circuit, which permits the exclusion of parasitic thermo emf's, by taking the average value of the results of two measurements for two different current directions. The magnitude of the thermo-emf in the circuit of the potentiometer itself consists of less than 1 μv and therefore, the inversion of the potentiometer working-current is not foreseen in the apparatus.

The circuit serving for the measurement of the emf of thermocouples has ten pairs of terminals for the connection of eight tested and two standard thermocouples. All the ten lines going from the terminals to which the thermocouples are connected are identical among themselves and can be alternately connected to the terminals X of the potentiometer through the thermocouple switch 2 and the polarity switch 4.

The magnitude of parasitic thermo-emf's in the measuring circuit is determined by means of the potentiometer in the apparatus by short circuiting the line conductors at the place where they are connected to the free thermocouple terminals.

The inside assembly of the apparatus is shielded. All the shields are connected amongst themselves and they are connected to the terminal "shield" at the back side of the apparatus.

The R2-A potentiometer, which is a modification of the R2/1 potentiometer, adapted for the given apparatus, has three measurement ranges: 1500, 150 and 15 mv. As in the R2/1 potentiometer, the first decade has fifteen, and the second, ten coils.

The microammeter, on which the indications of the automatic part of the potentiometer are read, has ten divisions with the zero mark at the beginning of the scale.

The smallest magnitude which can be read on the instrument is 1 μv.

The errors in voltage measurements performed by means of the R2-A potentiometer must not exceed in absolute value, the quantity calculated by the equation

$$\gamma=[0.2U_x+1.5A+1.5]\cdot 10^{-3} \text{ mv}$$

where U_x is the measured voltage in mv, and

A is the scale division of the first potentiometer decade.

The UVPT-1 device for checking secondary instruments is designated for checking automatic electronic potentiometers and bridges, millivoltmeters, ratiometers, and devices operating with rheostat data transmitters, for testing devices operating with inductive data transmitters, and for testing proportionality and stepping regulators. Moreover, direct current resistance can be measured by means of this device.

This device provides the possibility of simultaneous connection and testing of three instruments of the same or of various types, where the accuracy of readings of one instrument can be checked, while the testing of operation of the recording mechanism can be performed on the other two.

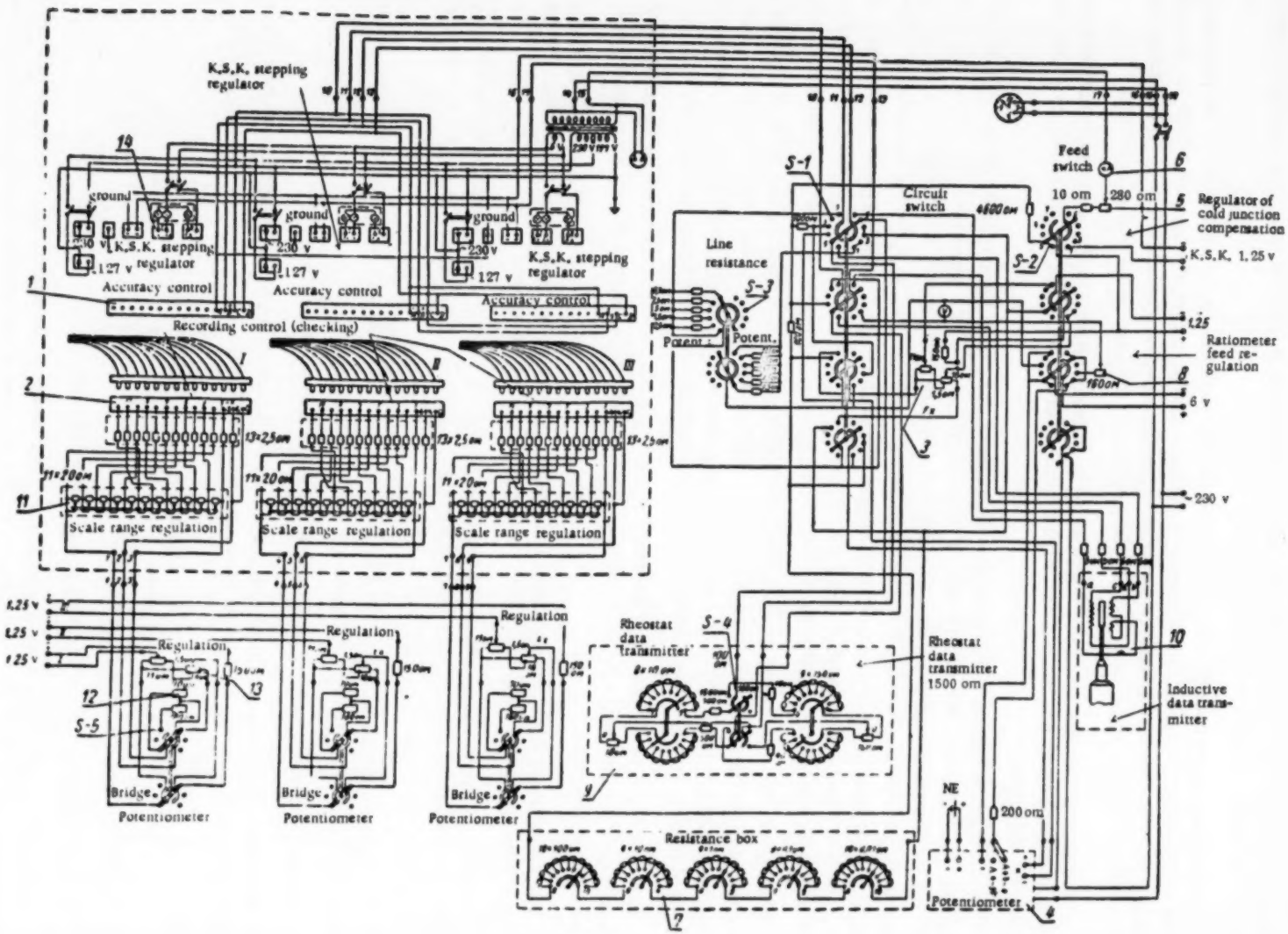
K,S,K, stepping regulator
ground
K,S,K, stepping regulator
Accuracy control
Recording control (checking)
Scale range regulation
Regulation
Bridge
Potentiometer
Rheostat data transmitter
Rheostat data transmitter 1500 om
Resistance box
Line resistance
Potent.
Circuit switch
Feed switch
10 om
280 om
Regulator of cold junction compensation
K,S,K, 1,25 v
Ratiometer feed regulation
6 v
230 v
Inductive data transmitter
NE
200 om
S-1
S-2
S-3
S-4
S-5

Fig. 2

The switching-over of multi-point instruments, after the check of reading errors was completed, to the verification of the quality of recording does not require any additional reconnection of terminals on the tested instrument.

The apparatus consists of two units: the measuring stand, where the standard measuring instruments are placed and a four-side revolving column on three sides of which the tested instruments are fastened. All the necessary switching and regulating devices are built into the apparatus. The column is made as a revolving one in order to provide the possibility of observing any of the three instruments.

The connecting of measuring and auxiliary circuits of the tested instruments is done by means of flexible cables having at one end cable lugs for the connection to the terminals of the tested instruments and at the other end, two-pin plugs for the connection to the plug blocks installed on the column panels.

The fastening of tested instruments on the column is done by means of special boxes. The apparatus is provided with nine boxes of three types which make it possible to fasten instruments of various dimensions by means of movable strips. In plant working conditions, the instruments removed from working places for repair or checking are put immediately into these boxes and transported to the corresponding room. During repair, checking, and calibration, the instrument remains in the box.

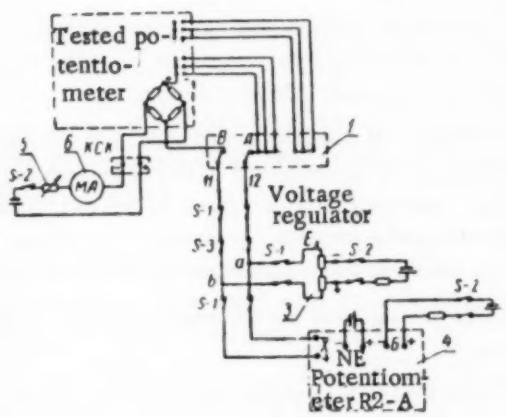

Fig. 3

The schematic circuit diagram of the apparatus is shown in Fig. 2 (the markings on Figs. 2, 3, and 4 are the same). The part of the circuit enclosed by a dotted line is mounted on the column.

The apparatus has four measuring circuits. Three of them are identical, and to them the tested instruments are connected when the operation of the recording mechanism is checked. The fourth – the main circuit of the apparatus – serves for the determination of reading errors of the tested instrument.

When the reading errors are determined, the tested instrument is connected to the main circuit of the apparatus through the terminals of block 1. The switching of the tested specimen from the basic measuring circuit to the circuit for recording control is done by switching the multi-pin plug from block 1 to block 2. The contacts A-1–12 in block 1 are shorted.

The main circuit of the measuring stand is universal. It can be a compensation circuit or a bridge circuit depending on the position of the main switches: "circuit switch" S-1 and "feed switch" S-2.

Figure 3 shows the circuit for checking potentiometers or millivoltmeters, which is formed in the measuring stand for the position 1 of the S-1 switch and positions 1 and 2 of the S-2 switch.

The voltage, which can be established by means of the voltage regulator 3 is fed to the terminals of the tested instrument, which are connected to the contacts A and B. The voltage is measured between points a and b (Fig. 3) by means of a standard potentiometer.

Depending upon the type of instrument tested, three cases of measurement are possible.

1. For checking electron potentiometers having a scale graduated in millivolts, the contacts A and B are connected directly to the corresponding terminals of the tested instrument. The switches S-1 and S-3 are placed in position 1 and the switch S-2, in position 2. The voltage across the terminals A and B, measured by the instrument which is being checked, is equal to the voltage measured by the potentiometer 4 between points a and b.

2. In checking electron potentiometers having a scale graduated in degrees, an additional bridge is introduced in the measuring circuit of the instrument, whose unbalanced voltage depends on temperature. This voltage balances the voltage created by the device built in the instrument, which serves for the compensation of temperature changes at the three ends of the thermocouple, so that it is possible to perform the checking

of the instrument without taking into account the temperature. The diagonal of the bridge is connected between the lug + B of the flexible cable and the (+) terminal of the tested instrument (Fig. 3); its other diagonal is fed from the auxiliary circuit of the apparatus (Fig. 2) through the block 14. The additional bridge must be placed inside the instrument in the immediate vicinity of the device for the compensation of temperature changes.

All four arms of the bridge circuit have an equal resistance (1 ohm) at the temperature of 0° C. Three of them are made of manganin and one of copper, and therefore, at any temperature different from 0° C, the equilibrium of the bridge is disturbed. The output voltage e appearing in the diagonal included in the measuring circuit will be equal to

$$e = U_0 \frac{\alpha t}{4 + 2\alpha t},$$

where $U_0 = I_0 r_0$ is the bridge input voltage,

$r = 1$ ohm is the over-all resistance of the bridge at 0° C,

α is the temperature coefficient of resistance for copper $- 0.004\ \text{deg}^{-1}$, and

t is the temperature of coils in the bridge in ° C;

or

$$e = U_0 \frac{t}{1000 + 2t}.$$

Changing the current intensity I_0 in the feed circuit of the bridge, it is possible to establish such conditions where the magnitude of e, in a certain temperature interval, is equal to the thermo-emf of the corresponding thermocouple for the same interval. On the scale of milliammeter 6 connected to the circuit of the cold junction compensation bridge, there are marks according to which, by means of the rheostat 5, the current intensity is established when the checking of instruments having standard Kh A, Kh K, and PP graduations is performed.

In this case, the voltage between points a and b, measured by the standard potentiometer, differs from the voltage at the terminals of the tested instruments by the amount e.

The introduction of a small bridge in the measuring circuit of the apparatus makes the checking easier. Additional chance errors do not exceed ± 1° C in this case. The usual method of checking, where the temperature inside the instrument is measured and the correction is calculated, does not introduce a lesser error and it lasts much longer.

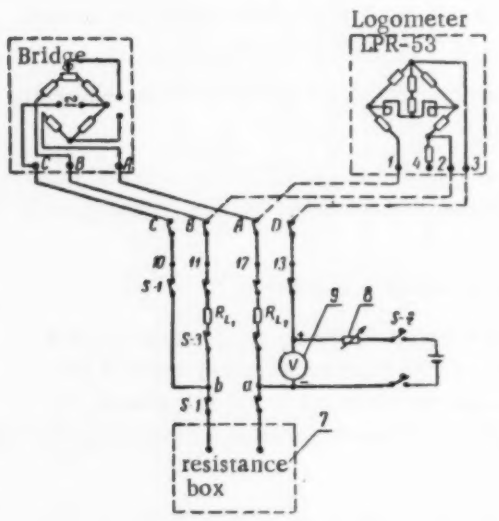

Fig. 4

3. When millivoltmeters are tested, the voltage at the instrument terminals differs from the voltage measured by potentiometer 4 between points a and b by the magnitude of voltage drop in the connecting conductors. A set of additional resistors built into the apparatus provides the possibility of testing instruments with line resistances of all ratings provided in the standards. The selection of resistor is performed by means of the switch S-3.

Figure 4 shows the circuit which is formed in the measuring stand of the apparatus for the position 2 of the switch S-1 and position 3 (for testing of ratiometers) or position 4 (for checking of bridges) of the switch S-2. Here, the tested bridge is connected to the terminals A, B, and C and the ratiometer, to the terminals A, B, and D of the flexible cable.

The standard resistance box 7 which basically replaces the resistance thermometer, is connected to the measuring arm of the tested instrument. The checking is

done by means of determining the resistance of the box, which is necessary for setting the instrument indicator against the scale mark which is being checked. By means of the switch S-3, resistance coils R, built into the apparatus, are connected to the circuit, and they are adjusted in such a way that the resistances between the terminal B of the flexible cable and point b (Fig. 4) and between the terminal A and point a are equal in absolute value, and their sum is equal to the nominal line resistance.

The resistance of conductors connecting points a and b with the standard box are included in the zero resistance and they are added to the box readings.

In testing ratiometers, the rheostat (8) provides the possibility of changing the feed voltage of the instrument by ± 20% for the determination of additional reading errors of the tested instrument.

The measurement of the millivoltmeter resistance is performed by the bridge circuit which is formed in the measuring stand for position 3 of the switch S-1 and position 5 of the switch S-2.

Two arms of the circuit consist of fixed resistors of 100 ohm built into the apparatus, the third arm consists of the internal resistance of the tested instrument, and the fourth arm is the standard resistance box 7 from which the magnitude of the measured resistance is read off. The equilibrium position of the circuit is determined according to the zero reading of the potentiometer 4, which is included in the measuring bridge diagonal. The feed is supplied to the bridge apexes from a battery of 1.25 v through limiting resistors.

For the checking of a stepping regulating device, on each of the three column sides there is an auxiliary circuit with colored pilot lamps which are lit when the corresponding regulator contacts are closed. The measuring circuit of the instrument whose stepping regulating device is being checked is connected to the main measuring circuit of the apparatus. Changing the values of quantities measured by the instrument and setting them according to the readings of standard instruments of the apparatus, it is possible to determine the regulating range of the stepping regulator.

The accuracy test of the proportionality regulator is performed when the switch S-1 is in position 4 and the switch S-2 in position 6 (Fig. 2). Thereby, a bridge circuit is established, whose two arms are formed by two parts of the regulator rheostat; the third arm is formed by the 100 ohm resistance built into the apparatus, and the fourth arm, by the standard resistance box 7.

The checking consists of the determination of inaccuracy in the position of the regulator brush with respect to the middle of the rheostat when the regulator index and the instrument indicator coincide. The terminals of the proportionality regulator are connected to the A, B, and C contacts of the block 1, while the terminal B is connected to the middle point of the regulator. Here, the measuring circuit of the instrument is not connected to the apparatus.

For the purpose of testing secondary remote control instruments, working as a unit with rheostat data transmitters, two special resistance boxes 9 enclosed in a common housing, which simulate the rheostat data transmitters by resistances of 100 and 1500 ohm, are built into the apparatus.

In the operation of instruments under working conditions, a change of the measured quantity causes a shift of the rheostat brush and a change in the ratio of resistances of both arms of the data transmitter, while its over-all resistance remains unchanged; the data transmitters, built into the apparatus, are constructed in a similar manner. They, like the scales of the tested instruments, are graduated in percentage ratios of arm resistances.

The tested instrument is connected to the terminals A, B, and C of the block 1, where the brush of the rheocord is connected to the terminal B. The switch S-1 is set in position 5 and the switch S-2 in position 4.

Depending upon the instrument parameters tested, the switch S-4 connects the built-in data transmitter of either 100 or 1500 ohm.

The checking of instruments working as a unit with inductive data transmitters is done by means of an inductive data transmitter 10 which is built into the apparatus. Here, the switch S-1 is placed in position 6 and the switch S-2, in position 3.

The primary windings of the instrument and the data transmitter are connected in series. The secondary windings are connected to form a differential circuit. The resistance of each line connecting the data transmitter with the instrument is equal to 5 ohm. The plunger of the data transmitter 10 is mechanically connected with a

micrometer screw, and when the latter turns, the plunger moves along its axis, which causes a corresponding motion of the plunger in the checked instrument. Here, the correctness of operation of the electrical circuit of the instrument is established, but the checking of the instrument scale is not performed.

For the checking of operation of the recording mechanism of multipoint self-recording instruments, three identical circuits are provided in the apparatus. The terminals of the tested instrument are connected to the contacts on the block 2. In order to create various deflections of the instrument indicator for lines of various numbers, the outlet leads from the multipoint rheostat 11 whose brushes are all mechanically connected among themselves, and are connected to the instrument terminals through block 2. The rheostat consists of 11 sections connected in series. The outlet leads from the rheostat brushes follow in such a sequence as to create the longest run of the carriage for points which are close to each other according to their numbers. By a turn of the handle, the over-all resistance of the rheostat can be made to correspond to the scale range of the tested instrument. In order to establish the initial reading of the instrument, a double rheostat 12, whose outlet leads are connected to the first pair of line contacts of the multipoint instrument, is connected in series to the rheostat 11. The double rheostat consists of two independent rheostats, one of which is connected to the circuit for the checking of bridges, and the other, for the checking of potentiometers, which is done by the switch S-5.

When potentiometers are checked, the voltage from the regulator device 13 is fed to the rheostats 11 and 12.

For the determination of motion speed of the strip chart in the tested instrument, electrical clocks are provided in the apparatus, which are synchronized with the frequency of the line feeding the tested instruments. Thus, in determining the chart speed, the influence of changes in the feed-line frequency is excluded.

SUMMARY

The first specimens of the described apparatus were produced by the Etalon plant of the VNIIM in high-temperature performance, and they were thoroughly tested. Thanks to their compactness, convenience in operation, and high checking accuracy, the apparatuses will undoubtedly find a wide application in the laboratories of the Committee system and in control laboratories of metallurgical plants.

The process of testing with both apparatuses is considerably speeded up thanks to a rational selection and arrangement of standard measuring instruments built into the apparatus, switching and regulating devices, and also thanks to the application of the semi-automatic standard R2-A potentiometer ZIP model.

According to sources in literature, an apparatus for testing secondary instruments has not been developed abroad.

The drawings of the apparatus are presently being handed over to a number of organizations in order to bring about its production in series.

OBJECTIVE SPECTROPYROMETER SPK-2

V. A. Kovaleskii and L. A. Boiarskii

The spectropyrometer installation SPK-1 [1] previously built in 1955 is being used successfully to transmit the scale of luminous temperature, to develop a color temperature scale and to investigate temperature lamps. In addition to this, it has lately been used to reproduce the international scale of luminous temperatures with the aid of a method developed by one of the authors [2].

All this has created grounds for the further adoption of objective methods for the measurement of high temperatures in calibration work. In connection with this a new spectropyrometric system SPK-2, Fig. 1, has

been designed in the Khar'kov State Institute of Standards and Measuring Instruments (KhGIMIP), intended, as was the SPK-1, for the calibration and testing of standard and sample temperature lamps used for measuring temperature by means of brightness and color. In its construction the new spectropyrometric system is basically similar to SPK-1, which has been previously described in detail [3, 4], however basic improvements have been made in the construction of some of the units.

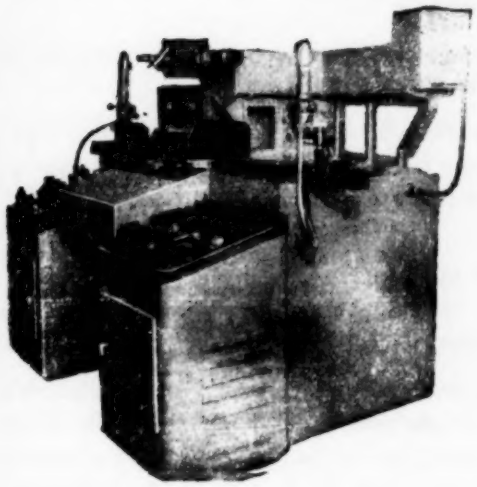

Fig. 1

In the SPK-2 the monochromator is placed in the top panel in order to insure convenient access to the photocell and to permit visual observation of the spectrum during the calibration of the monochromator. In the capacity of an optical bench we use the standard rails produced by the optical-mechanical factory; this permits us by means of standard aids to fasten the auxiliary devices and details (filters, lenses, etc.). We exclude from the temperature lamp installation mechanisms complicated and expensive remote-control devices. Also in a more convenient location in comparison with respect to the SPK-1 are the potentiometer galvanometer, the electronic system, the reference winding resistors and other units.

In the SPK-2 system a modulator of new construction is used with an oscillating mirror similar to the mirror system used in electromagnetic oscillographs, which directs a beam of light alternately to the monochromator slit from each of the two sources that are being compared.

The mirror is glued to two thin tungsten wires, 20 microns in diameter, which pass between the poles of a permanent magnet. Alternating current from the voice-frequency generator passes through the wires and forces the mirror to oscillate.

When the mirror is stationary each beam of light occupies half of the monochromator collimator objective. When the mirror oscillates the light beams replace each other in succession. If the light intensity of the two lamps that are being compared is the same, then the parts of the objective that are being illuminated by the different lamps blend together, no visible boundary being formed between the two parts. The objective appears to be uniformly illuminated for any position of the oscillating mirror. This system satisfies the requirements that have been placed upon the modulator, in order to insure high-precision in the measurements [4].

The new modulator possesses a series of basic advantages over the modulator of the SPK-1 system. It operates more reliably, does not require any adjustment or regulation and permits us to obtain a high-quality image of the temperature lamps, also the microscope possesses a large field of view to be used in focusing. This permits accurate focusing upon the object being measured and is basically very important for work with a model of the absolute blackbody.

A series of changes has also been made in the construction of the exterior optical system (Fig. 2).

The light beams from the filaments of the temperature lamps 1 pass through the objective 2 and fall upon the separating prism 3 which has exterior illumination. The diaphragm 4 prevents light from the right lamp from falling upon the left objective, and vice versa. Light beams reflected from the prism fall upon the modulator mirror 5.

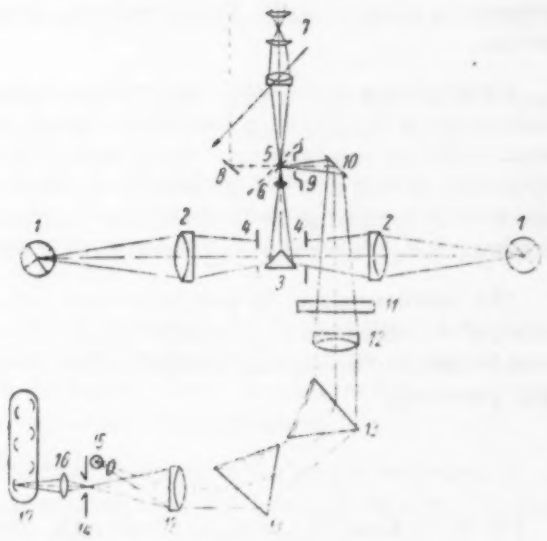

Fig. 2

The lens 6 is mounted before the mirror, and it gives an image of the edges of the prism 3 in the plane of the diaphragm of the collimator objective of the monochromator 12.

In contrast to SPK-1 the objectives 2 can be moved along the optical axis, which insures a rapid and convenient focusing system and allows us to change the size of the lamp images within wide limits.

In the plane of the mirror 5 reduced-size images of the filaments of both temperature lamps 1, which are superimposed upon each other, are examined with the aid of the microscope 7.

The modulator mirror is seen in the background of the lamp images; this permits us to see directly which part of the lamp filament is being processed in the mirror and used for measurement.

The microscope is mounted in a movable frame; thanks to this it can be moved (in a direction indicated by the arrow) to a second position, so that the images from the entrance slit 9 and the mirror 5 in the monochromatic light of the lamp due to the reflected ray 15, fall upon the field of view of the microscope with the aid of the mirror 8.

The entrance slit of the monochromator is placed directly next to the mirror 5, and, in distinction to the slit of the SPK-1 system, its width may be varied; this facilitates the calibration of the monochromator and allows us, when necessary to increase our accuracy in determining the effective wavelength.

The light beam reflected from the mirror 5 passes through the entrance slit, is reflected from the mirror 10, passes through the photographic plate holder for the light filter 11 and falls upon the collimator objective of the monochromator 12. The photographic plate holder 11 serves at the same time as the shutter for the monochromator. Then the ray passes through the monochromator prism 13, the objective 12, exit slit 14, lens 16 and falls upon the photo-multiplier cathode 17, type FEU-17 or FEU-22.

In the figure the path of the rays is shown according to convention. In reality the path of rays 5-10 and 10-8 is perpendicular to the plane of the figure, so that ray 3-5 passes under ray 10-12.

A series of changes has also been introduced into the electronic system of the installation. The most substantial of these consists of a new switching arrangement for the pass-band of the low-pass filter. In agreement with the new scheme all the filter capacitors, corresponding to the various band frequencies, each through a separate resistor, are always set to the output of the synchronous detector. The input to the final amplifier together with equal intensity indicator may, with the aid of the switch, be connected to any unit of the filter.

Charge accumulates uniformly on all the filter condensers, i. e., the averaging of the current from the output of the synchronous detector occurs simultaneously, regardless of the cell to which the final amplifier is connected. Due to this the indications of the equal intensity indicator for any value of the pass-band may be read at once following the connection of the input to the final amplifier to the corresponding capacitor, while previously, in order to do this, it was necessary to wait for the period of time that was required to charge the capacitor.

Investigations of the SPK-2 system have showed that its basic metrological characteristics – sensitivity and occasional errors in comparing intensities – are of the same type as are characteristic of the SPK-1 system, and conform to the set requirements. The sensitivity of the system consists, depending upon the wavelength and temperature, of from 2 to 100 divisions in the scale of the equal intensity indicator, going to 1°. The root mean square error in comparing the temperatures as determined by the light intensity for a constant setting of two temperature lamps, for a wide temperature range and long waves, is 0.05°.

The installation may be used to measure luminous temperature; in this application the accuracy of the pyrometric measurements significantly exceeds the accuracy obtained by the best visual pyrometers. The introduction of installations such as the SPK-2 raises considerably the level of metrological work in the sphere of optical pyrometry.

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EXPERIENCE IN MEASURING THE TEMPERATURE OF LIQUIDS BY MEANS OF THERMISTORS

V. S. Senin

The main advantage of thermistors as compared with thermocouples and metal thermometers consists in their high sensitivity which approaches 2-6% of the initial resistance per 1° C of temperature change. That is why an increasing interest is being displayed in the use of thermistors [1, 2, 3].

Below, we give measurement results of temperatures of liquids by means of thermistors in an experimental equipment under the following conditions:

the temperature of the liquid was measured in the limits of − 20 to + 100° C,

the pressure of the liquid during testing was within the limits of 1 to 80 kg/cm^2,

the speed of the flow at the place of measurement was 8-10 m/sec,

the total duration of measurement was 15-60 sec, and

the distance of the measured object to the instrument panel was 20 m.

In order to decrease the inertia of the measuring device it would have been preferable to have used bare thermistors. However, due to the thermistors' being affected by pressure as well as by temperature [1] a glass-enclosed thermistor of Soviet make type T8R was used. The basic data of the T8R thermistor are: resistance of 500 to 700 ohms at 20° C, temperature coefficient of 3-4% per 1° C, and the temperature range of − 100 to + 120° C.

Special checking of the hermetic sealing of a transducer with a T8R element showed that loading made no difference to the reading of the transducer.

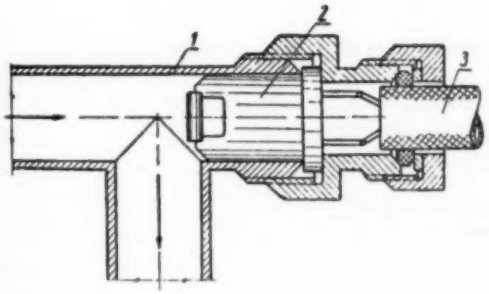

Fig. 1. Diagram of a temperature transducer installation. 1) T-piece, 2) temperature transducer, 3) measuring cable.

The method of connecting a transducer to the mains through which the liquid is flowing is shown in Fig. 1.

Readings were registered on an electronic "Lenteplopribor" type EMP-209 automatic bridge with strip-chart recording. Three additional resistances were connected at the input of the instrument (Fig. 2).

By varying resistors R_s and R_a it is possible to change within wide limits the range of measurements and the sensitivity of the system. Obviously, this facility is especially useful for experimental measurements.

In the tests described in this article the values of these resistors remained in the limits of: R_s = 100-200 ohms, R_a = 10-100 ohms, R_i = 4.3 kilohms.

In order to determine the errors of measurement by means of this method, tests were made with the temperature of the liquid varying between − 10 and + 80° C. Results thus obtained showed that the mean square error in this range of temperatures did not exceed ± 0.5° C.

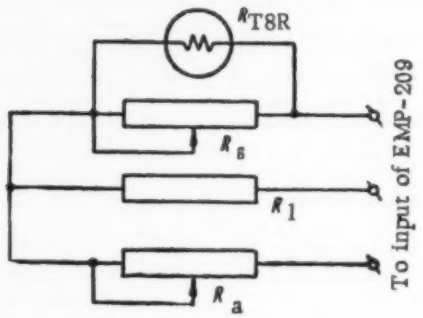

Fig. 2. A method of connecting the temperature transducer to instrument EMP-209. R_{T8R}, is the measuring thermistor; R_1, the resistance limiting the current through R_{T8R}; R_s, the wire-wound variable resistance for setting the temperature range; R_a, the wire-wound variable resistance for setting the required lower limit of measurement of the automatic bridge.

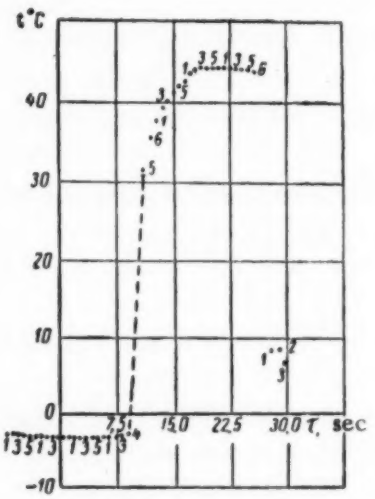

Fig. 3. Temperature of liquids measurement results.

In order to determine the stability of the system it was recalibrated after a month's operation. The tests showed that the calibration had remained practically unchanged.

As the result of tests the measuring time of a transducer immersed in a stationary liquid was determined as $\tau \simeq 2$ sec with a temperature change of 60° C.

A three-months' experience has shown that the measuring device provided reliable measurements of the temperature of liquids in the experimental equipment and was simple to use.

Figure 3 shows test results of one of the temperature of liquids measurements. The time of operation of the equipment was 17 sec and the temperature of the liquid was changed from − 3 to + 44° C. It will be seen from the graph that despite the relatively short duration of the experiment the measuring device provided a reliable determination of the temperature of the liquid in a stable-state condition of the equipment.

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SURFACE THERMOCOUPLES

E. S. Shpigel'man

Experience has shown that the dispersion of temperature values (determined as the difference between the maximum and minimum value of ten consecutive measurements) of surface thermocouples obtained at a constant surface temperature amounts to 30-40° C for temperatures of the order of 200° C and is considerably larger for higher temperatures, and that the temperature lag amounts to 1-3 minutes.

For accurate surface temperature measurements thermocouples must possess a reproducibility of results of the order of 1-2° C and their heating-up time must not exceed 20-25 sec.

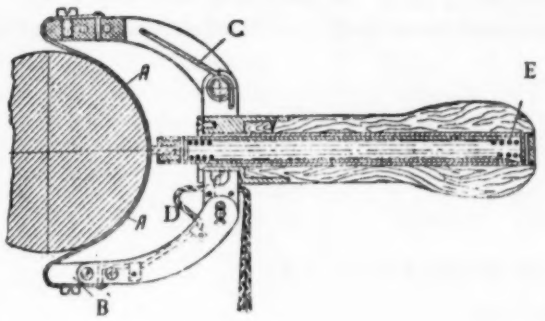

Fig. 1

Below we describe two thermocouples which satisfy these requirements.

The band thermocouple (Fig. 1) consists of two tapes 0.2 mm thick (in order to decrease the heat inertia) and 5 mm wide. One of the tapes is made of chromel and the other of alumel, which are welded together and then rolled into a strip (any suitable material can be chosen for the electrodes). Strip A is strung over a special holder which consists of a handle and of two ebonite shoes C, held apart by means of springs B. When the thermocouple is placed on a cylindrical surface the springs tension the strip and thus ensure that it makes contact with the surface over a considerable area. Opposite the junction of the tapes a ceramic knob is fixed to the center of the holder; the knob presses the junction by means of spring E tightly against the surface whose temperature is being measured. This arrangement improves considerably the reproducibility of the electromotive force values.

The free ends of the tapes are soldered to copper-constantan compensation leads D of 0.5 mm diameter.

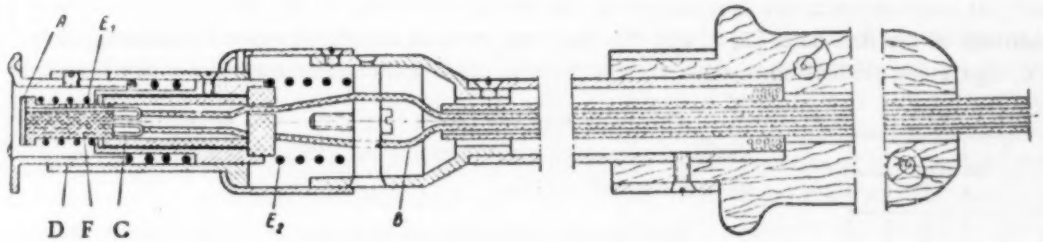

Fig. 2

The disc thermocouple (Fig. 2) consists of a copper disc A, 0.5 mm thick and 7 mm in diameter, with four holes into which four electrodes C (for averaging out the disc temperature) are soldered in (two iron and two constantan of 0.3 mm in diameter), taken out through channels in an asbestos-cement cylinder F and connected to compensation leads B in like pairs. Springs E_1 and E_2 ensure a constant contact of the heat-sensitive element with the measured surface. The disc and the electrodes are protected against mechanical damage by an external metallic covering D.

The investigation of the surface thermocouples was carried out by means of steam thermostats ("Measurement Techniques," No. 4, p. 76, 1956).

In order to evaluate the efficiency of these thermocouples their quality factor which characterized their thermal resistance was determined from the formula

$$K = \frac{E_n}{E_m},$$

where K is the quality factor,

E_n is the value of the electromotive force when the thermocouple was placed on the reference surface of a steam thermostat, and

E_m is the value of the electromotive force at the same temperature, but taken from the calibration curve for the given thermocouple materials.

Thermocouples for which $K \geq 0.9$ provide a dispersion of readings not exceeding 2° C at t = 450° C.

As the result of tests of above thermocouples it has been established that the error of temperature measurements of metallic surfaces in the range of 100-500° C does not exceed ± 1.5% for the disc thermocouple and ± 2.5% for the band thermocouple, and that the heating-up time amounts to 15-20 and 25-30 seconds, respectively.

CHARACTERISTIC THERMAL INERTIA CURVES OF CONVENTIONAL THERMOCOUPLES AND RESISTANCE THERMOMETERS

G. M. Levin and V. I. Vol'mir

As the result of investigating conventional thermocouples and resistance thermometers [1] we have plotted characteristic curves of the relation between the thermal inertia factor ϵ (sec) and the thermal dissipation coefficient α (kcal/m²·hr·° C); these curves (Figs. 1, 3, and 4) which have been given in part in [1] were obtained experimentally at room temperature (approximately 18-20° C) according to the theory and methods of the regular thermal conditions of the first order [2, 3, and 4]; they can serve as a reliable guide for choosing thermal receivers and comparative evaluation of their thermal inertia under different heat-exchange conditions.

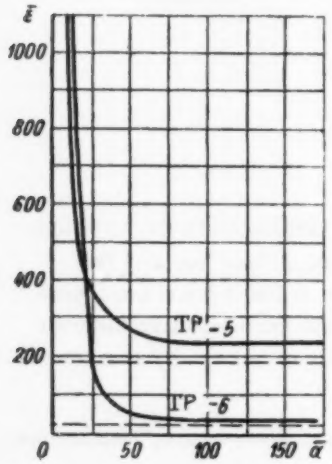

Fig. 1. TP-5 is thermocouple TKhK-621; Tc-6 is thermocouple TKhK-UXV.

On our curves and tables symbols $\bar{\epsilon}$ and $\bar{\alpha}$ denote the arithmetic mean of numerous measurements for which the relative mean square error did not exceed 3-4%.

Having first measured or evaluated α for a given condition, it is possible to find the characteristic curve corresponding to the value of ϵ for a given temperature-measuring instrument, to select the required instrument and calculate

$$\tau_y = \varepsilon \ln \frac{|(t-u)_0|}{|\Delta t|},$$

where τ_y is the time required for obtaining a reading taken from the instant a regular thermal condition has been established (sec),

$(t-u)_0$ is the difference in temperature between the medium and the thermal receiver at the instant when regular thermal conditions are established (° C),

Δt is the value of the instrument-readings "lag," which can be taken as the permissible error, i.e., as the quantity (t-u) ° C, which can be neglected in these measurements.

Tentative values of α (kcal/m^2·hr·° C) measured by means of an alpha-calorimeter are given in Table 1.

TABLE 1

Medium	Thermal receivers with porcelain tips D_t = 20 mm	Thermal receivers with metal tips		
		cylindrical D_t = 20-23 mm	cylindrical D_t = 14-15 mm	conical
Boiling water, molten metal, ice and water mixture, energetically stirred water	∞	∞	∞	∞
Still water, t ≃ 20° C,	350-400	175-185	150-175	175-250
Transformer oil, t ≃ 20° C, medium intensity stirring	100-125	70-80	80-100	50-125
Still transformer oil, t ≃ 20° C	45-55	30-40	35-45	25-40
Still air, t ≃ 20° C,	10-11	3.5-4.5	5.0-5.5	3.0-4.5
Operating space of a tubular oven hermetically closed at the ends, t ≃ 600-700° C	100-130	80-100	–	150-200

For a correct evaluation of the thermal receiver inertia under known conditions of operation, when irregularities of the medium temperature and large differences between it and room temperature are possible, it is necessary to carry out additional testing of the receiver with the object of being able to plot a complete cooling (or heating-up) curve of the instrument, i.e., of the relations between $\log_e$ (t-u) and time τ, starting from the moment the instrument is set in its operating condition or the temperature condition of the medium changes. Such a curve obtained according to the established universal method of a regular thermal condition [2] provides corrections for quantities ϵ and τ_y and makes it possible to evaluate the character and duration of the thermal conditions preceding the regular state.

It is possible tentatively to introduce certain corrections, for instance, for a transition from a constant temperature of the medium (i.e., from the conditions under which the characteristic curves are plotted) to a linearly changing temperature, on the basis of data obtainable from the technical literature [5].

Investigations of the effect of high temperatures and the constructional peculiarities of the temperature-measuring devices on their inertia have shown that the effect of various factors on their inertia is not always correctly evaluated.

Effect of constructional peculiarities. In order to decrease the thermal inertia of the thermal receivers designers strive to obtain a good contact between the heat-sensitive element and its covering, paying considerably less attention to the value of the thermal conductivity between the remaining parts and to the relation between the specific heat of various elements.

Such an approach was the result of the essence of the standard specifications GOST 6616-53 and GOST 6651-53, which provide for testing of the temperature measuring devices' inertia at high values of α only (in

boiling water, and ice and water mixture), when the effect of even a heavy metal cover is small and the contact of the sensitive element with the cover ensures a relatively rapid establishment of the instrument readings with the required accuracy ("ten percent lag").

TABLE 2

TKhK-UXV, l_p = = 100 mm		TKhA-UXV, l_p = = 200 mm		TKhK-621 (TP-5)		TP-8		ETP-XXII		ETM-XI	
$\overline{\alpha}$	$\overline{\tau}$	$\overline{\alpha}$	$\overline{\tau}$	$\overline{\alpha}$	$\overline{\tau}$	$\overline{\alpha}$	$\overline{\tau}$	$\overline{\alpha}$	$\overline{\tau}$	$\overline{\alpha}$	$\overline{\tau}$
∞	24.3	∞	32.4	∞	191	∞	122	∞	13.1	∞	54.4
175	36.2	195	41.7	181	228	181	128	242	50.0	260	92.2
42.9	55.0	125	50.9	77.2	240	84.4	142	43.6	194	90	141
24.8	216	30.7	132	34.3	321	34.3	222	37.2	364	40.0	229
3.2	2480	4.3	1670	4.4	2070	4.3	1270	4.0	2000	2.5	1840

A more detailed examination of this question throws a different light on it. The pronounced effect of the thermal inertia factor ϵ on quantity α, shown in the characteristic lag curves, has been theoretically proved and experimentally demonstrated [1, 2, 3]. These curves have a hyperbolic shape and can cross each other, i.e., depending on the size, shape, configuration and thermal characteristics of their components, thermal receivers which had greater inertia than the remaining ones at high values of α (under standard test conditions) could have smaller inertia than the remaining ones at medium or small values of α (under operation conditions). Thus, the data on the inertia of thermal receivers obtained under standard conditions can be wrong for actual operating conditions of thermocouples or resistance thermometers.

Quick-response thermocouples types TKhK-UXV and TKhA-UXV and resistance thermometers type ETP-XXII can serve as an example of this phenomenon. Owing to the good contact between their elements and covering, these instruments have a relatively small inertia at large values of α. When medium and small values of α are measured, however, the bulk of their metal casings begins to tell and their inertia becomes equal to and even exceeds that of the ordinary slow-responding instruments (Table 2).

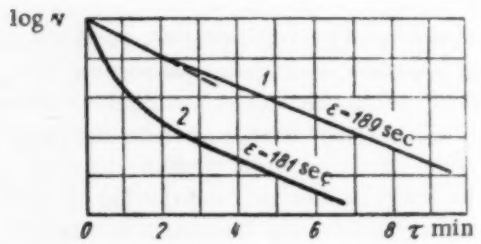

Fig. 2. 1) Bead; 2) thermo-sensitive element.

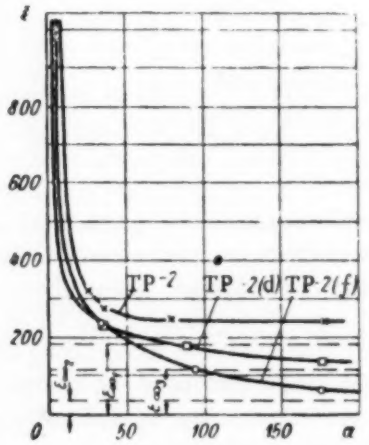

Fig. 3

The standard testing methods introduce additional errors due to their conventional criterion ("ten percent lag") and failure to account for irregular operating conditions.

Let us introduce the following notations: τ is the time, and ϑ is the difference of temperature between the surrounding medium and some thermal receiver point, which is a function of time and the coordinates of the point.

If under conditions of intensive heat exchange a cooling curve is plotted on semi-logarithmic paper for a thermal-receiver sensitive element which has a relatively good contact with its cover and another curve for its insulating bead, we shall obtain results shown in Fig. 2. Here k is the coefficient which can be chosen on the basis of convenient plotting to fit different curves.

The introduction of coefficient $\underline{k}$ leads to a shifting of the origin of the coordinates without changing the shape of the curve or the angle it makes with the X axis, i.e., without changing the value of ϵ which is of interest to us.

In the course of the tests we carried out, quantity ϑ changed between 8 and about 0° C at room temperatures, and between 150 and about 0° C at higher temperatures.

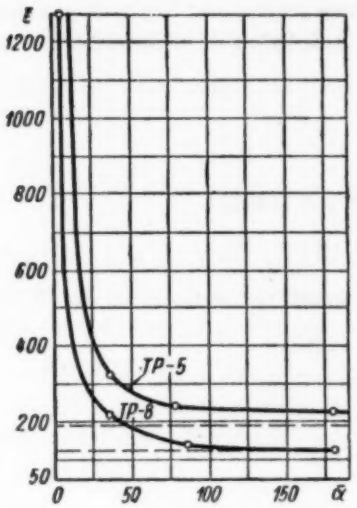

Fig. 4

TABLE 3

Instrument tested	$\overline{\epsilon}$	$\overline{\epsilon}_{20}$	$\overline{\epsilon}_{700}$
TKhA-XIII	~ 90	240	105
TKhA-I	~115	150	69
TKhK-621	~ 90	240	106
TKhA-UXV	~180	45	49

The standard technique consists in assuming that almost from the start of the experiment the cooling curve is linear. In practice, however, the irregular operation (the curved portion of the characteristic) is lasting and pronounced for a thermo-sensitive element. Owing to this phenomenon the instrument readings, which are recorded according to the standard technique and affected by the temperature of the sensitive element, may relatively quickly reach the "ten percent lag." This speed of operation gives a false idea of the inertia of the instrument, since the subsequent equalization of temperatures between the thermo-sensitive element and the medium will proceed much slower, and will be determined (with constant external conditions) not only by the good contact of the element with the case, but also by the sum of the thermal, geometrical and other characteristics of the thermal receiver.

Figure 3 gives the test results of a stock thermocouple TKhA-XIII (TP-2), and of the same thermocouple with a foil placed between the junction and the case, TP-2 (f) and finally of the same couple filled with alcohol right up to the edge of the case, TP-2(a). Tests have demonstrated the effect of the thermal contacts on inertia.

In order to check the effect of the thermal capacity of the internal components on the thermal inertia of the instruments, comparative tests were made with a double thermocouple TKhK-621 (TP-5) against the same instrument but without one of the thermocouples and with the four channel porcelain beads changed for single channel tubes, TKhA-II (TP-8). It will be seen from Fig. 4 and Table 2 that a decrease in the thermal capacity of internal components leads to a sharp fall in the inertia at all the values of α.

Effects of temperature. The transition from measurements at room temperatures, to which the universal method of setting the thermal operating condition is limited, or from the range of 0 to 100° C recommended by the GOST's, to higher temperatures, at which most of the industrial thermocouples are used, must lead to a change in the external conditions of heat exchange, a rise in heat dissipation and also to an increase in the heat dissipation inside the instrument.

Tests of thermocouples at temperatures of the order of 600-700° C have shown (Fig. 3) that at the same value of α the thermal inertia ϵ of the greater part of the instrument is considerably lower at high temperatures than at room temperature.

This relationship has been confirmed by numerous experiments with industrial thermocouples separated from the remaining parts of the instrument (the results of these experiments have not been included in Table 3). Thermocouple TKhA-UXV is exceptional, it has the value of $\overline{\epsilon}_{700}$ slightly higher than that of $\overline{\epsilon}_{20}$; in this thermocouple a good contact between all the components is ensured especially between the bulky case and the junction, and it would appear therefore that a rise with temperature in the thermal capacity of the components balances out the increased heat dissipation inside the instrument.

SUMMARY

The characteristic lag curves, plotted according to the universal method of a regular thermal condition, are a reliable guide for a physical classification of thermal receivers, for comparing their inertia, for a correct choice and improvement of their construction, but they must be supplemented by tests of the exact conditions of the instrument's application, in particular at appropriate temperatures; check-test determination of the thermal inertia of temperature-measuring devices according to the GOST methods carried out "in mass production are only designed for checking their assembly and not as an indication of their behavior under different operating conditions" [3].

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ELECTRICAL MEASUREMENTS

THREE-TERMINAL SMALL-VALUE CAPACITORS

A. L. Grokhol'skii

For checking various instruments measuring small capacities the Novosibirsk State Institute of Measures and Measuring Instruments developed a set of three-terminal small-value capacitors type KME-4, described below, which have a nominal direct capacity ranging from 0.0001 to 1 $\mu\mu$f.

The construction of one of the capacitors is shown in Fig. 1. It consists of a cylindrical body 1, which carries, on steotite insulators 2, fixed to the body by spring-loaded nuts 3, two electrodes 4 and 5. Electrode 5 can be displaced for fine adjustment by turning nut 6, which has a spring to eliminate backlash.

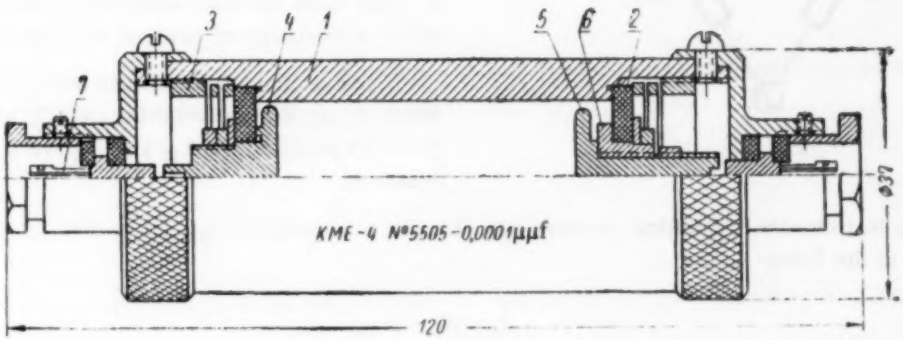

Fig. 1

The capacitor is connected to the circuit by means of two sockets 7. Some of the capacitor components are silvered and others are chromium plated.

The capacitor of such a design has three capacities: the direct capacity C_{12}, which corresponds to the nominal value and two partial capacities C_{13} and C_{23}.

The direct capacity is formed by electrodes 4 and 5, which have no direct contact with the body of the capacitor. This capacity in type KME-4 capacitors varies according to the exponential law in relation to the distance between the electrodes.

The partial capacities are formed by electrodes 4 and 5 and the capacitor body 1, which serves as the third electrode. They amount to 10-20 $\mu\mu$f thus exceeding considerably the direct capacity.

The partial capacities also consist of the capacities of the connecting devices, whose value depends on the depth of insertion of the plugs into sockets 7 and on their mutual position. This capacity varies in the limits of 0.1-0.5 $\mu\mu$f.

The capacitor is closely approximated by the equivalent circuit shown in Fig. 2. The circuit shows, in addition to the capacities already mentioned, resistances R_{13} and R_{23} equivalent to the losses in the supporting insulators.

L_1 and L_2 represent the inductances of the connecting links from the electrodes to the sockets.

Resistances r_1 and r_2, represent in addition to the resistances of the links, which are very small, the contact resistances in sockets 7, which, with bad contact surfaces, may amount to 0.1 ohm.

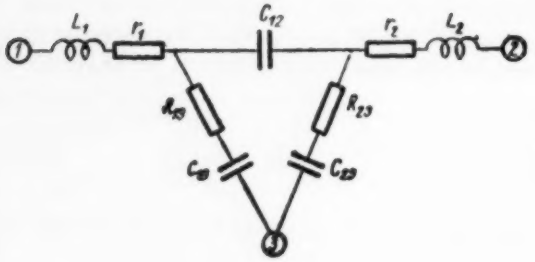

Fig. 2

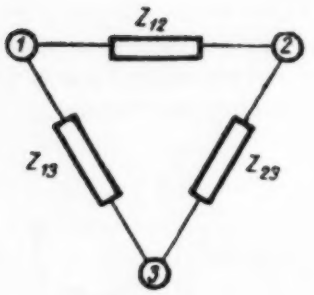

Fig. 3

The properties of the three-terminal capacities are used to the full with special instruments which measure the direct capacity without determining the values of the partial capacities. Such instruments include special bridges, the "Kimel" direct capacity measuring instrument, and the recently produced precision set "Pimel" which incorporates inductive ratio arms. This instrument satisfies the international specification for measuring the inter-electrode capacities of electron tubes.

The three-terminal capacitors are connected to the set by means of three conductors consisting of two coaxial cables. The central conductors of the cables are connected by means of plugs to sockets 7. The cable screens are connected to the spring bushing of the capacitor thus forming the third connecting line.

The peculiarities of the operation of small capacities at 1 Mc have not been sufficiently dealt with in literature and it is advisable to analyze this problem in detail.

Let us convert the circuit of Fig. 2 into an equivalent triangle of impedances (Fig. 3) where Z_{12} is the direct impedance and Z_{13} and Z_{23} are the partial impedances.

Since the instruments in question measure only the direct impedance Z_{12}, let us find its value only, which can be written in the form:

$$Z_{12}=R_{12}-jx_{12}, \tag{1}$$

where

$$R_{12}=2\,r_1\left(1+\frac{C_{13}}{C_{12}}\right), \qquad x_{12}=\frac{1}{\omega C'_{12}}, \tag{2}$$

hence the effective direct capacity is

$$C'_{12}=\frac{C_{12}}{1-2\,\omega_2\,L_1\,(C_{12}+C_{13})}. \tag{3}$$

Using (2) and (3), we obtain

$$\operatorname{tg}\delta=2r_1\omega C_{12}+2r_1\omega C_{13}. \tag{4}$$

Expressions (2), (3), and (4) have been derived assuming the circuit to be symmetrical when $r_1 = r_2$, $L_1 = L_2$, and $C_{13} = C_{23}$. In calculation second order terms were omitted, which is permissible for industrial capacitors of the type KME-4.

It follows from (3) that the effect of partial capacities on the value of the effective direct capacity depends on the square of the frequency.

It will be seen from (4) that tan δ depends on the value of the contact resistance in the capacitor connecting-leads and may reach a considerable size at high frequencies.

Resistances R_{13} and R_{23} are equivalent to the dielectric losses in the capacitor and have no effect on either C_{12} or tan δ.

The set of capacitors KME-4 is certified at 1000 cps with an error from 0.1 to 2% (at a capacity of 0.0001 $\mu\mu$f). This calibration holds at higher frequencies as well since the frequency error of the capacity does not exceed 0.01% at frequencies of the order of 1 Mc if $C_{13} \leq 20\ \mu\mu f$ and $L_1 < 60 \cdot 10^{-9}$ h.

Some of the highly stable capacitors investigated in operation could be calibrated with greater precision. The NGIMIP disposes of reference capacitors of small values, which have an error between 0.01 and 0.1%, and of a measuring bridge with a limiting sensitivity of $(0.5\text{-}1) \cdot 10^{-18}$ f.

ELECTRONIC DIVIDERS WITH DIGITAL CONVERSION

V. B. Smolov

Among the measuring devices used for continuous systems' control, there are those designed for dividing two quantities $\underline{x}$ and $\underline{y}$ given in the form of two dc voltages U_x and U_y.

The quotient

$$z = \frac{x}{y} \equiv \frac{U_x}{U_y} \tag{1}$$

must be automatically converted into a number of pulses N with an accuracy of the order of 0.1 to 1.0% of Z_{max}:

$$N \equiv z. \tag{2}$$

The solution of this problem by the conventional methods used in the computor technique requires the use of dividers and digital converters. Such devices are rather complicated. Below we examine certain methods of solving this problem by means of time-pulse devices.

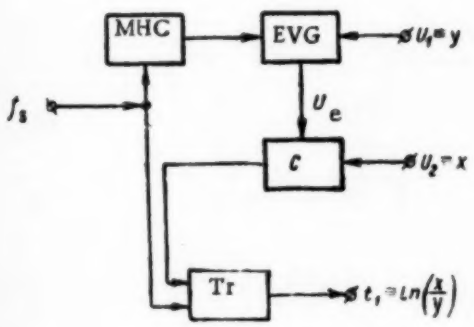

Fig. 1

Measurement by means of time-pulse devices consists in converting, in the first instance, a continuous quantity Θ into a time interval $\underline{t}$: $\Theta \equiv t$ (time modulation) and then measuring interval $\underline{t}$ by means of a chronographic electronic circuit which provides a number of pulses $N \equiv t$.

In this instance, the converter must have a characteristic of the form

$$t = k_1 \frac{U_x}{U_y} = k_2 \frac{x}{y}. \tag{3}$$

By combining such a converter with an electronic counting circuit it is possible to obtain an electronic divider with digital conversion.

1. Let us examine a method of designing a dividing converter with a logarithmic scale:

$$z = \ln\left(\frac{x}{y}\right). \tag{4}$$

Such a device must contain a logarithmic converter which fulfills the transformation of the type:

$$t \equiv \ln x - \ln y\,. \tag{5}$$

A block schematic of such an element is shown in Fig. 1 and the corresponding time diagram in Fig. 2.

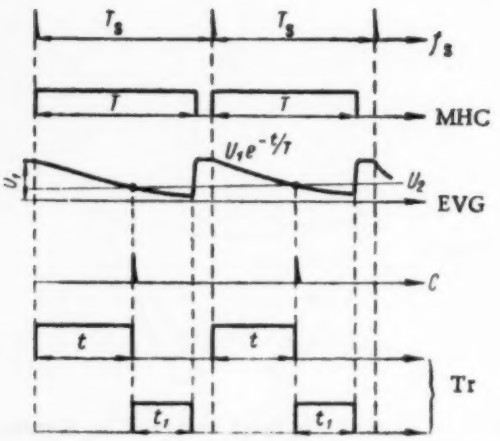

Fig. 2

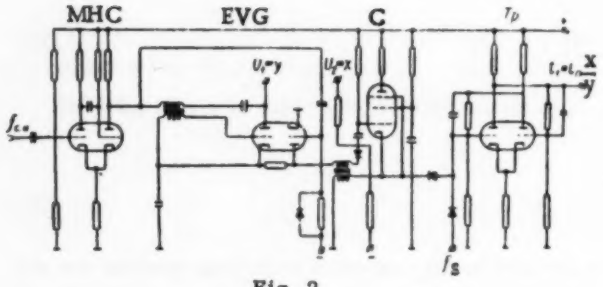

Fig. 3

The synchronizing pulse f_s controls the multivibrator hold circuit MHC and trigger T.

The exponential voltage generator EVG controlled by the multivibrator MHC produces a voltage of the form

$$U_e = U_1 e^{-t/\tau}, \tag{6}$$

which is compared with voltage U_2 by means of the comparator C.

At the instant the equality

$$U_e = U_2 \tag{7}$$

is attained, the comparator produces a short pulse which is fed to the trigger control.

The duration of the rectangular pulses taken off the anodes of the trigger is equal to t and $t_1 = T - t$ (Fig. 2).

The use of either of these intervals will provide the characteristic expression of (5).

It can be easily seen that

$$\left.\begin{aligned} t &= -\tau \ln\left[\frac{U_2}{U_1}\right]; \\ t_1 &= T + \tau \ln\left[\frac{U_2}{U_1}\right]. \end{aligned}\right\} \tag{8}$$

In order to be able to use (8) for simulating (4), it is necessary to choose correctly the scale of the converter.

Let

$$\left.\begin{aligned} U_2 &= \frac{x}{m_x}, \\ U_1 &= \frac{y}{m_y}, \\ t_1 &= \frac{z}{m_z}, \end{aligned}\right\} \tag{9}$$

where m_x, m_y, and m_z are the scales of the logarithmic converter.

By substituting (9) in (4), we obtain:

$$t_1 = \ln\left(\frac{m_x}{m_y}\right) \cdot \frac{1}{m_z} + \ln\left(\frac{U_2}{U_1}\right) \cdot \frac{1}{m_z}\,. \tag{10}$$

In order to make (10) and (8) identical, it is necessary that

$$\tau = \frac{1}{m_z},$$
$$T = \tau \ln\left(\frac{m_x}{m_y}\right). \tag{11}$$

Equation (11) determines the choice of the logarithmic divider scale and of its main element parameters.

One of the possible circuits for the logarithmic converter is shown in Fig. 3.

This converter has a wide passband of the order of hundreds of kc.

2. If, in the above dividing-converter circuit (Fig. 3), the exponential voltage generator is changed for a generator with a linearly increasing or decreasing voltage, the circuit becomes a continuous linear-scale device.

Moreover

$$U_{\text{lin}} = U_1 \frac{t}{T}.$$

At the instant of equality,

$$U_{\text{lin}} = U_2, \quad t = T\frac{U_2}{U_1} = \frac{U_2}{U_1}.$$

In order to ensure the working of the dividing-converter circuit, it is necessary that

$$(U_1)_{\max} = (U_2)_{\min}$$

Hence

$$\frac{m_x}{m_y} = z_{\max}$$
$$m_z = \frac{z_{\max}}{T}. \tag{12}$$

In order to ensure accurate logarithmic or linear converters based on the circuit in Fig. 3, it is necessary to use stable and accurate exponential or linear generators, and this is one of the defects of such converters.

By using feedback it is possible to design a dividing converter with a linear scale which will require a considerably less stable linear generator.

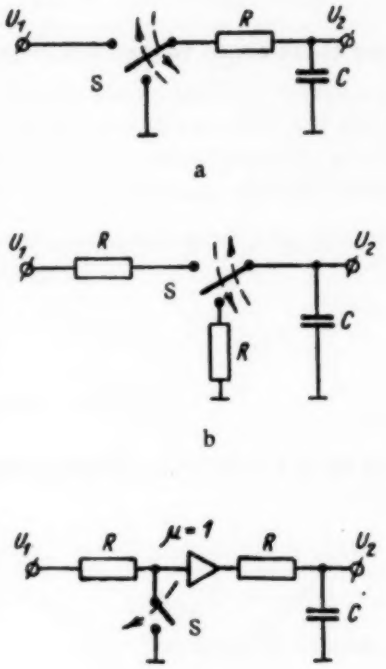

Fig. 4

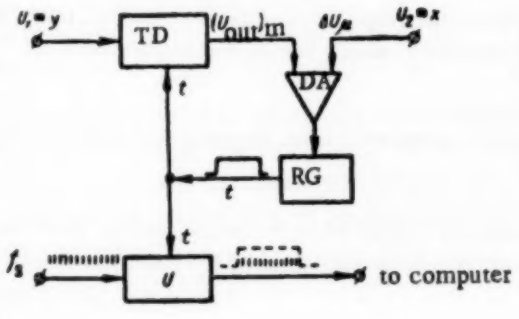

Fig. 5

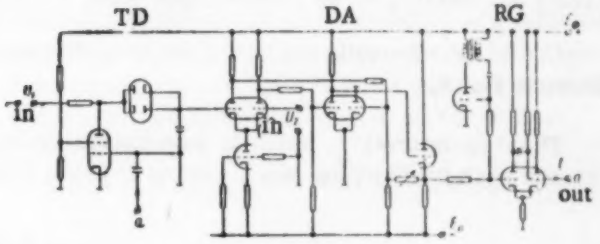

Fig. 6

3. There exist devices which can transform a time interval $\underline{t}$ into a dc voltage proportional to the duration of the interval [1]:

$$U_{out} \equiv t.$$

Several schematics of such circuits are shown in Fig. 4. These time demodulators contain an electronic switch S controlled by rectangular pulses of variable duration. Any tube circuit can be used as an electronic switch [1] providing it has a small resistance in the closed,and a high resistance in the open,position.

The controlling rectangular pulses of variable duration charge and discharge capacitor C by means of the electronic switch.

In the stable-state condition of the demodulator operation,the value of the output voltage will be proportional to the duration of the controlling pulses:

$$(U_{out})_m = U_1 \frac{t}{T}, \tag{13}$$

hence

$$t = T \frac{(U_{out})_m}{U_1}. \tag{14}$$

Thus, the time demodulator can be used as a time duration converter.

A converter circuit based on a time demodulator is given in Fig. 5.

The output voltage $(U_{out})_m$ of the time demodulator TD is compared by a differential amplifier DA with voltage U_2 which is proportional to the dividend $\underline{x}$. The voltage difference

$$U_2 - U_1 \frac{t}{T} = \Delta U$$

is amplified and controls the generator RG of rectangular pulses, whose duration is equal to:

$$t \simeq a \Delta U.$$

These pulses in turn control the time demodulator, so that Eq. (13) remains valid.

Since, owing to the presence of feedback and a large amplifier gain the voltage ΔU approaches zero, we have

$$U_2 = U_1 \frac{t}{T};$$

$$\text{and, } t = T \frac{U_2}{U_1} \equiv \frac{x}{y}.$$

Thus, the circuit consisting of the time demodulator, differential amplifier,and generator of rectangular pulses of variable duration, is a linear dividing converter with feedback which lowers the requirement of accuracy and stability of the circuit components.

One of the schematic circuits of the time duration converter based on a time demodulator with feedback is shown in Fig. 6.

The time interval $\underline{t}$, which is proportional to the quotient,is converted in the same manner as in the previously examined circuits into a number of pulses which are fed to a computer or a transmission line.

LITERATURE CITED

[1] Generation of Special-Shape Oscillations [In Russian] ("Soviet Radio" Press, 1952).

HIGH- AND ULTRAHIGH-FREQUENCY MEASUREMENTS

PRECISION TUBE VOLTMETER FOR COMPARATIVE MEASUREMENTS

M. E. Gertsenshtein

Audio-frequency voltage measurements are mostly comparative; the voltmeter is fed by signals of a constant frequency and waveform and the amplitude relations are measured. This is the case in all the microwave measurements when the envelope of the microwave voltage does not change during measurement, in unbalanced bridge circuits, and when measuring gain.

In relative measurements the voltmeter only need have a linear relation between its reading α and the input voltage U_0

$$\alpha = kU_0. \tag{1}$$

where k is a constant.

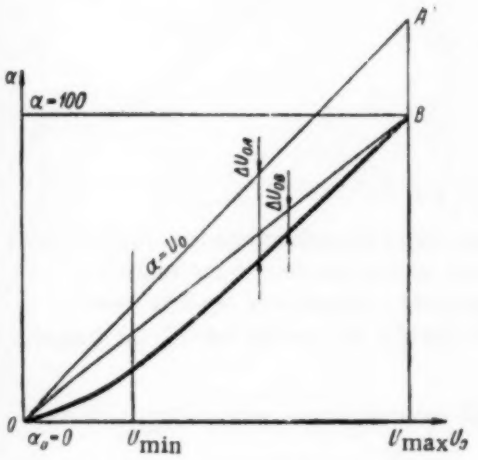

Fig. 1. Characteristic of a detector tube. OA ($\alpha = U_0$) is the characteristic of an ideal peak voltmeter k = 1; OB is the linear approximation of a detector characteristic; ΔU_{OA} is the nonlinear characteristic.

A dc instrument is connected to the output of the tube voltmeter; in principle it is, of course, possible to recalibrate the instrument scale so as to meet requirement (1). This, however, is undesirable: the operation of such an instrument is inconvenient since the nonlinear parameters of the circuit are not sufficiently stable. It is desirable to use a dc scale without introducing any corrections for nonlinearity.

Instruments based on comparative measurements are not affected by frequency or waveform errors, and provide, as it will be shown below, the possibility of improving considerably their accuracy.

The linearity of the mass-produced instruments is insufficient for accurate measurements; thus, according to specified values, microvoltmeter 28IM has a deviation from linearity of 2.5%.

Let us analyze the reasons for the nonlinearity of the amplitude characteristic of a tube voltmeter. Let us assume that the indications of the pointer instrument α are proportional to the direct current i flowing through it, i.e., that the indicating instrument does not distort the amplitude characteristic.

The detection of an ac voltage is accompanied by nonlinear distortion. The characteristic of a rectifying diode (Fig. 1) is, in general, nonlinear. For (1) to hold, the detector characteristic should be a straight line over the operating portion and should pass through the origin of the coordinates. If there is an amplifier in front of the detector, the nonlinearity of the amplitude characteristic of the former also becomes a source of error.

Let us find an approximate expression for the detector characteristic of the tube connected according to the circuit in Fig. 2. If

$$\omega RC \ll 1. \tag{2}$$

it is possible to consider the ac and dc circuits separately. The voltage U(t) at the anode of the tube consists of a dc and an ac component:

$$U(t) = U + U_0 \cos \omega t. \tag{3}$$

The diode works mostly with a negative voltage on the anode and the volt-ampere characteristic of the tube can be taken as

$$i(t) = i[U(t)] = i_0 e^{\gamma U}, \tag{4}$$

where $\gamma = \frac{e}{kT_k}$,

e is the electron charge,

k is the Boltzmann constant,

T_k is the cathode temperature, and

i_0 is the tube initial current.

Averaging over one period we obtain [1] an equation for the rectified voltage:

$$\frac{U}{i_0 R} e^{\gamma U} = I_0(\gamma U_0), \tag{5}$$

where $I_0(\gamma U_0)$ is a modified Bessel function. The full current of the instrument is

$$i_{in} = \frac{U}{R} + i_k = \frac{U + U_k}{R}, \tag{6}$$

$$a \simeq i_{in}$$

$$U_k = i_k R.$$

where i_k is the current supplied to the instrument by the zero adjustment circuit.

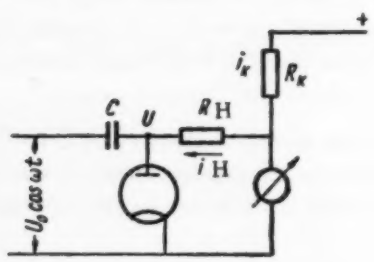

Fig. 2. Rectifier tube circuit.

Since the internal resistance of the instrument is always much smaller than R_H and R_k, current i_k is equivalent to the additional voltage U_k at the anode of the tube. Henceforth, we shall take U to be the total voltage which provides the current through the instrument.

With variation of U_k the detector characteristic (Fig. 1) shifts bodily up or down.

If there is no alternating voltage fed to the tube, the diode will have a certain voltage U_H due to the thermal energy of the electrons, and

$$i_0 R = U_H e^{\gamma U_H}, \tag{7}$$

U_H grows with the emission current and the load resistance R. Equation (5) can be written in the form:

$$\frac{U}{U_H} e^{\gamma (U - U_H)} = I_0(\gamma U_0). \tag{8}$$

In order to obtain an amplitude characteristic with a small nonlinearity, it is necessary to work with large amplitudes: $\gamma U_0 \gg 1$.

Let us use the asymptotic representation for $I_0(\gamma U_0)$:

$$I_0(\gamma U_0) \simeq \frac{e^{\gamma U_0}}{\sqrt{2\pi\gamma U_0}}. \tag{9}$$

From (9) and (5), we obtain:

$$\gamma(U - U_0) = \gamma U_н + \ln\frac{U_н}{U} - \frac{1}{2}\ln 2\pi\gamma U_0. \tag{10}$$

Inserting $U = U_0$ into the right-hand side of the equation, we obtain for the effective value of the diode voltage:

$$U = U_0 + U_н - \frac{1}{\gamma}\ln\frac{U_0}{U_н} - \frac{1}{2\gamma}\ln 2\pi\gamma U_0 + U_k. \tag{11}$$

Let us stress that (11) holds with $\gamma U_0 \gg 1$. The amplitude of the alternating voltage U_0 appears in the right-hand side of (11) in a nonlinear expression as a $\log_e$ and hence the relation $U(U_0)$ can be represented by a straight line only approximately.

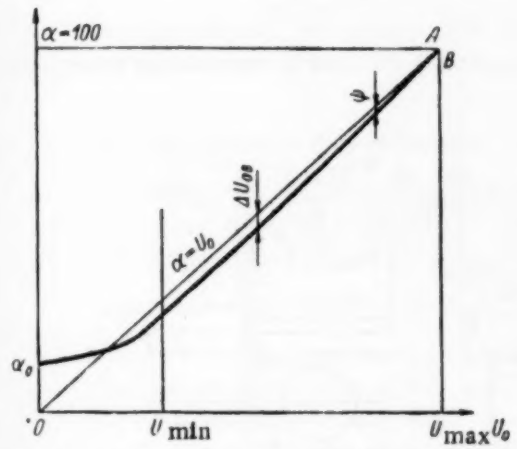

Fig. 3. Detector tube characteristic at $\alpha \neq 0$.

Let U_{max} and U_{min}, the largest and smallest values of the alternating voltage amplitude U_0, be the limits of the operating voltages.

From (11) we obtain for the error ΔU_{OA}:

$$\Delta U_{OA} = U_н + U_k - \frac{1}{\gamma}\ln\frac{U_0}{U_н} - \frac{1}{2\gamma}\ln 2\pi\gamma U_0. \tag{12}$$

In order to obtain ΔU_{OB}, it is necessary to subtract from ΔU_{OA} the distance between the straight lines. After simple transformations we obtain:

$$\Delta U_{OB} = \left(1 - \frac{U_0}{U_{max}}\right)\left\{U_k + U_н - \frac{1}{\gamma}\ln\frac{U_{max}}{U_н} - \frac{1}{2\gamma}\ln 2\pi\gamma U_{max}\right\} - \frac{3}{2}\frac{1}{\gamma}\ln\frac{U_{max}}{U_0} \tag{13}$$

It follows from (13) that if U_k is chosen so as to make the expression in figure brackets equal zero, the straight lines OA and OB (Fig. 1) will coincide and the relative error will be:

$$\delta_1 = \frac{\Delta U_{OB}}{U_{max}} = -\frac{3}{2}\frac{1}{\gamma U_{max}}\ln\frac{U_{max}}{U_{min}}. \tag{14}$$

The detecting characteristic of the tube for this instance is shown in Fig. 3.

The ratio U_{max}/U_{min} is usually given: γ is determined by the cathode temperature; hence, in order to decrease δ_1, it is necessary to increase U_{max}. If $U_{max}/U_{min} \simeq 3$,* $\gamma = 10$ 1/v (T = 700° C), $U_{max} = 70$ v effective, δ_1 will equal 0.15%. In deriving the formula we took the volt-ampere characteristic (4) which only holds if, at any phase of the alternating voltage, the anode is negative with respect to the cathode. Since the current flows through the tube in short pulses, the instantaneous value of the current is much larger than its mean value. Even during the passing of the pulse, the anode should be negative with respect to the cathode; hence a tube with a large splash current is required.

It will be seen from (14) that the generally accepted practice of adjusting the zero of a tube voltmeter at $U_0 = 0$ is incorrect. With such an adjustment $U_k + U_H = 0$; the expression in the figure bracket is not zero which produces an additional error δ_2 equal to:

* If $U_{max}/U_{min} > 3$, potential dividers should be used at the input of the instrument; such a circuit is used in instruments 28IM and LV-9.

$$\delta_2 = -\left(1 - \frac{U_0}{U_{max}}\right)\frac{1}{\gamma U_{max}}\left(\ln\frac{U_{max}}{U_{min}} + \frac{1}{2}\ln 2\pi\gamma U_{max}\right) \quad (15)$$

For the case examined above, δ_2 amounts to about 0.8%, i.e., much larger than δ_1.

It will be seen from Fig. 3 that if the straight lines OA and OB coincide, the detecting characteristic will cross the approximating curve at point B in an upward direction. Hence, if α_0 is slightly increased the detecting characteristic will rise, angle ψ will become smaller and so will the error. The minimum error obtainable with an optimum adjustment of voltage U_k can be derived from formula:

$$\delta_{min} \simeq \pm 0{,}1\,\frac{1}{\gamma U_{max}}\left(1 - \frac{U_{min}}{U_{max}}\right)^2. \quad (16)$$

Formula (16) is obtained by developing ΔU_{OB} into a series at point $U_0 = U_{max}$. For the example quoted when $U_{max} = 70$ v effective, $\delta_{min} \simeq \pm 0.01\%$. With relatively small voltages at the tube (for instance 7 v effective) the quantity δ_{min} amounts to $\pm$ 0.1%.

Thus, by a correct zero setting, it is possible to decrease considerably the error in comparative measurements.

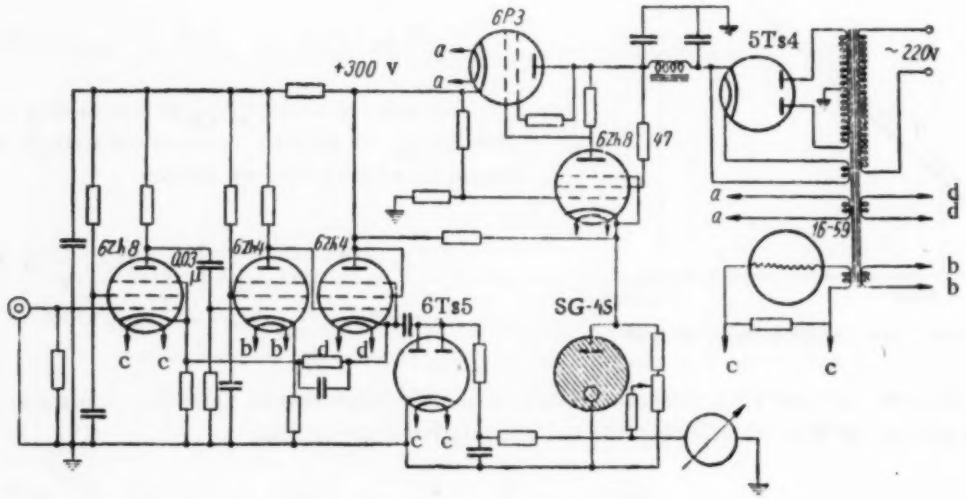

Fig. 4. Schematic of a precision model voltmeter for comparative measurements.

Above considerations were checked experimentally. The schematic of the voltmeter model is shown in Fig. 4. Diode 6Ts5 was used as a rectifier with a barretter-stabilized heater. The maximum value of the sinusoidal voltage at the diode was 80 v. A portable 50 μa instrument type LM grade 0.5, with a mirror scale of 100 divisions and an error not exceeding 0.2% for comparative measurements was used. The input voltage was amplified in a three-stage amplifier with a feedback, which decreased the gain by about 40 db, i.e., $1 + k\beta \simeq 100$.

Working without a feedback, and an amplitude of 60 v effective at the output, no distortions were noticeable on an oscillograph, i.e., the coefficient of nonlinear distortion was less than 5%. Since feedback decreases distortion by a factor of $1 + k\beta$ at a constant output level [2], the nonlinear distortion of the amplifier must amount to < 0.05%.

This method of determining nonlinear distortion does not take into account distortions due to lag nonlinearity [3]. With a varying signal strength the power dissipated in the feedback resistors also varies, changing their resistance and hence the gain. Since a high value resistance will heat up more than a low one, providing its temperature coefficient is positive, the gain will rise with an increasing signal amplitude.

It would appear from tests described below that the lag nonlinearity does not affect accuracy.

A circuit for checking the linearity of the instrument is shown in Fig. 5. The potential divider R_3, R_4 was made up of resistance boxes type RMS; a constant voltage at its input was maintained with aid of an auxiliary tube voltmeter 2 with an extended scale, and was kept constant within 0.3 of a division by means of resistance box R_5. The zero was set at $U_0 = 0$, ($R_4 = 0$); the pointer was set to $\alpha_0 = 0$, 0.5, and 1; next, the pointer was set to the maximum deflection $\alpha_{max} = 100$. By varying resistor R_3 various values of α were obtained. Measurements were made at 620 cps in order to avoid beating with supply frequency harmonics.

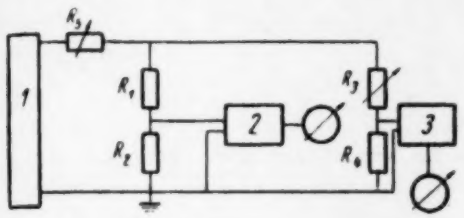

Fig. 5. Block schematic of the measuring circuit. 1) Oscillator 3G-10; 2) auxiliary voltmeter; 3) voltmeter under test.

Theoretical values of α_{th} corresponding to an ideal linear instrument, with characteristic curve OB, were calculated from formula:

$$\alpha_{th} = 100 \frac{R_3^0 + R_4}{R_3 + R_4}, \qquad (17)$$

where R_3^0 is the value of resistor R_3 at $\alpha = 100$.

The error was taken to be equal to the difference:

$$\Delta = \alpha - \alpha_{th}.$$

These measurements showed that the optimum value of α lies between 0.5 and 1 near to 0.8.

The results of tests made with $\alpha_0 = 0.8$ showed that the error in the operating range of 25-100 divisions does not exceed 0.2%. A further adjustment provides even a smaller error; this, however, cannot be attained owing to the error of the indicating instrument itself. At $\alpha_0 = 0$ the error reaches 0.7%.

Owing to the large feedback, frequency does not affect the instrument readings up to 20 kc.

Thus the theoretical assumptions have been completely justified. Owing to the technique of adjusting the pointer of the instrument (at $U_0 = 0$) to a certain graduation, instead of zero, it was possible to increase considerably the accuracy of the instrument. The position of this graduation is determined once only when the instrument is calibrated. If the input voltage has a meandering waveform the positions of the graduation will change a little.

It will be seen from (13) and (14) that with large voltage amplitudes at the diode the instability of the diode parameters is not important; thus with a change in the cathode temperature of 10% the error did not exceed 0.1%.

Above instrument was stable in operation and there was no drift of one voltmeter with respect to another during one hour. In the instrument and feedback-circuit models, resistances type BS were used; in order to increase stability, high-wattage wire-wound resistors should be used.

SUMMARY

The simple method, justified theoretically in this article and verified in practice, of improving the linearity of tube voltmeters by a better setting of the zero, permits one to use mass-produced dc instruments without any recalibration of the scale, which is especially important when a recording instrument whose recalibration is difficult is used at the output of the voltmeter.

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EFFECT OF THE MEASURED VOLTAGE WAVEFORM ON THE READINGS OF A DIODE PEAK VOLTMETER

A. M. Fedorov

It appears from the experience of measuring high-frequency voltages by means of diode voltmeters that there is a considerable dispersion in readings when measuring the same voltage values at frequencies differing from each other by a few percent only. There is, however, no correct explanation of this phenomenon in the technical literature.

The present article provides, by means of the theory of resonance errors, an explanation of this phenomenon, which takes place not only in diode voltmeters, as such, but also in voltmeters forming part of standard oscillators and of certain power meters.

It is known that the relative resonance error of diode voltmeters when their high-frequency circuit can be represented by an equivalent homogeneous line with distributed constants is expressed by the formula:

$$\theta_1 = \frac{1 - \cos\frac{\pi}{2}\frac{f}{f_p}}{\cos\frac{\pi}{2}\frac{f}{f_p}} 100\%. \tag{1}$$

where f is the frequency at which the resonance error of the voltmeter is determined, and

f_p is the resonance frequency of the voltmeter.

If the high-frequency circuit of the voltmeter can be represented as an equivalent circuit with lumped parameters, the relative resonance error will be expressed by the formula:

$$\theta_1' = \frac{\left(\frac{f}{f_p}\right)^2}{1 - \left(\frac{f}{f_p}\right)^2} 100\%. \tag{2}$$

Formulas (1) and (2) have been derived on the assumption that the ac resistance of the high-frequency circuit of the voltmeter is small as compared with its reactance.

Let us examine the effect of the harmonic of the voltage on the value of the resonance error.

Let us assume that the high-frequency circuit of the diode voltmeter is equivalent to a homogeneous line with distributed constants.

If, at the input of the diode voltmeter, the amplitude of the fundamental is a, and that of the harmonic is b, the amplitude of the fundamental between the anode and cathode will be:

$$a' = \frac{a}{\cos\left[\frac{\pi}{2} \cdot \frac{f}{f_p}\right]} \tag{3}$$

and the amplitude of the n-th harmonic will be:

$$b' = \frac{b}{\cos\left[\frac{n\pi}{2} \cdot \frac{f}{f_p}\right]}. \tag{4}$$

Moreover, across the anode-cathode circuit there will always be a voltage antinode for any of the harmonics.

The distribution of the fundamental and harmonic waveforms with respect to their phases can be most diverse. Hence, when the phase relation between the fundamental and harmonics is unknown, it is only possible to determine the maximum deviation of the resonance error of a diode voltmeter with a purely sinusoidal signal whose harmonics are due to the resonance error. In order to simplify the analysis let us assume that there is only one higher harmonic. It is easy to see that these maximum deviations of the resonance error will occur when the maximum fundamental voltage will be in phase or anti-phase with the maximum harmonic voltage. These two cases are shown for the second and third harmonics in Figs. 1 and 2, and analyzed in the article.

It can be shown that the fundamental resonance error of a diode voltmeter in the presence of the n-th harmonic is determined from the formula:

$$\theta_n = \left\{ \frac{a}{a \pm b} \cdot \frac{1 - \cos\left[\frac{\pi}{2}\frac{f}{f_p}\right]}{\cos\left[\frac{\pi}{2}\frac{f}{f_p}\right]} \pm \frac{b}{a \pm b} \cdot \frac{1 - \cos\left[\frac{n\pi}{2}\frac{f}{f_p}\right]}{\cos\left[\frac{n\pi}{2}\frac{f}{f_p}\right]} \right\} \cdot 100\%. \qquad (5)$$

Then the relative additional resonance error due to the n-th harmonic will be expressed by the formula:

$$\Delta\theta_n = \theta_n - \theta_1 = \left\{ \frac{\mp b}{a \pm b} \cdot \frac{1 - \cos\left[\frac{\pi}{2}\frac{f}{f_p}\right]}{\cos\left[\frac{\pi}{2}\frac{f}{f_p}\right]} \pm \frac{b}{a \pm b} \cdot \frac{1 - \cos\left[\frac{n\pi}{2}\frac{f}{f_p}\right]}{\cos\left[\frac{n\pi}{2}\frac{f}{f_p}\right]} \right\} \cdot 100\%. \qquad (6)$$

If the high-frequency circuit of the diode voltmeter can be represented by an equivalent circuit with lumped constants, the formulas for θ_n' and $\Delta\theta_n'$ can be represented in the form:

$$\theta_n' = \left\{ \frac{a}{a \pm b} \cdot \frac{\left(\frac{f}{f_p}\right)^2}{1 - \left(\frac{f}{f_p}\right)^2} \pm \frac{b}{a \pm b} \cdot \frac{\left(\frac{nf}{f_p}\right)^2}{1 - \left(\frac{nf}{f_p}\right)^2} \right\} \cdot 100\%, \qquad (7)$$

$$\Delta\theta_n' = \left\{ \frac{\pm b}{a \pm b} \cdot \frac{\left(\frac{f}{f_p}\right)^2}{1 - \left(\frac{f}{f_p}\right)^2} \pm \frac{b}{a \pm b} \cdot \frac{\left(\frac{nf}{f_p}\right)^2}{1 - \left(\frac{nf}{f_p}\right)^2} \right\} \cdot 100\%. \qquad (8)$$

In Formulas (5) - (8) the top signs correspond to the case when the maximum values of the fundamental and the harmonic across the anode-cathode circuit are in phase, and the lower sign when they are in anti-phase.

Above formulas hold when the values of $\frac{nf}{f_p}$ are not too close to unity $\frac{nf}{f_p} < 0.7$, and it is possible to neglect the ac resistance of the input high-frequency circuit of the voltmeter.

Figure 3 shows the relation between the additional resonance error due to the second harmonic (with varying percentage content) and the ratio $\frac{f}{f_p}$. Figure 4 shows the same relation due to the presence of the third harmonic in the signal.

These curves (Figs. 3 and 4) show that even with a small harmonic content at the input of the diode voltmeter the resonance error can vary considerably as compared with that due to a pure sine wave, and that the additional resonance error due to the presence of harmonics can be of the same order as the error due to a pure sine-wave signal.

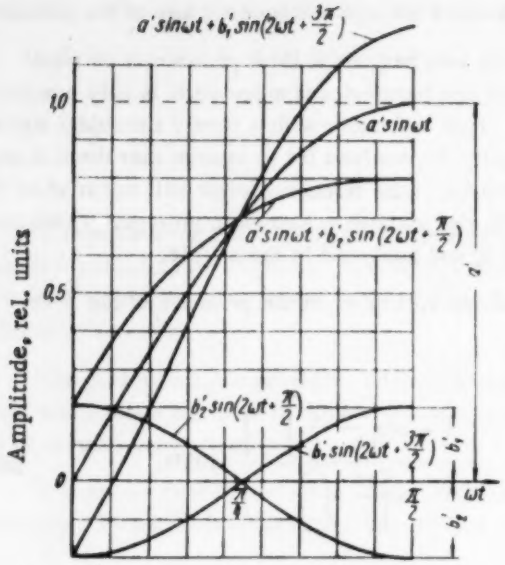

Fig. 1. Graph of a signal containing the first and second harmonics.

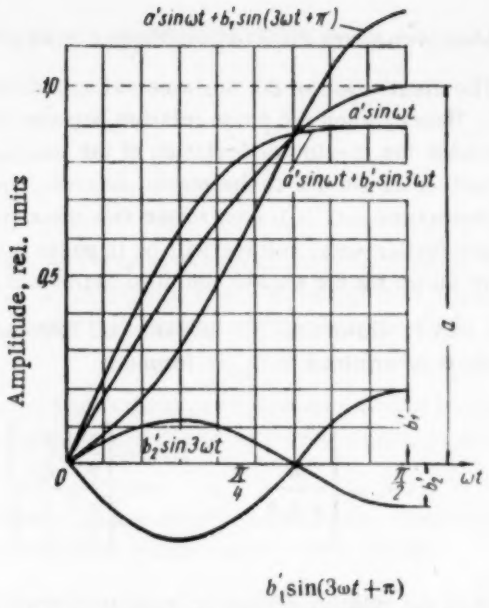

Fig. 2. Graph of a signal containing the first and third harmonics.

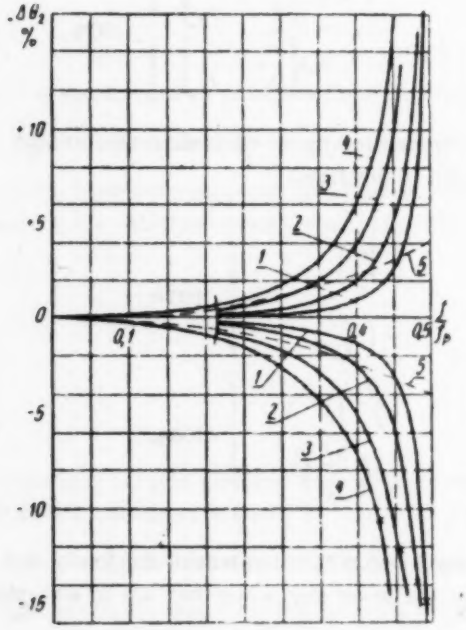

Fig. 3. Relation between the additional resonance error due to the second harmonic, when it is present in the measured voltage, and the ratio of f/f_p. 1) With 0.5% second harmonic content; 2) with 1% second harmonic content; 3) with 2% second harmonic content; 4) with 3% second harmonic content; 5) with

$$0{,}1\left[\frac{1-\cos\left(\frac{\pi}{2}\cdot\frac{f}{f_p}\right)}{\cos\left(\frac{\pi}{2}\cdot\frac{f}{f_p}\right)}\right]100\%.$$

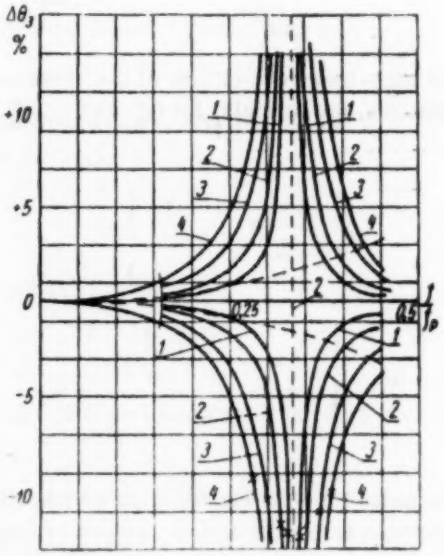

Fig. 4. Relation between the additional resonance error due to the third harmonic, when it is present in the measured voltage, and the ratio f/f_p. 1) With 0.5% third harmonic content; 2) with 1% third harmonic content; 3) with 2% third harmonic content; 4) with 3% third harmonic content; 5) with

$$0{,}1\left[\frac{1-\cos\left(\frac{\pi}{2}\cdot\frac{f}{f_p}\right)}{\cos\left(\frac{\pi}{2}\cdot\frac{f}{f_p}\right)}\right]100\%.$$

The auxiliary oscillators used in experimental determination of a resonance error produce, as a rule, in addition to the fundamental, harmonics which cause variations in the resonance error. This explains the phenomenon of the large dispersion of the resonance error obtained experimentally for the same diode voltmeter at the same frequency.

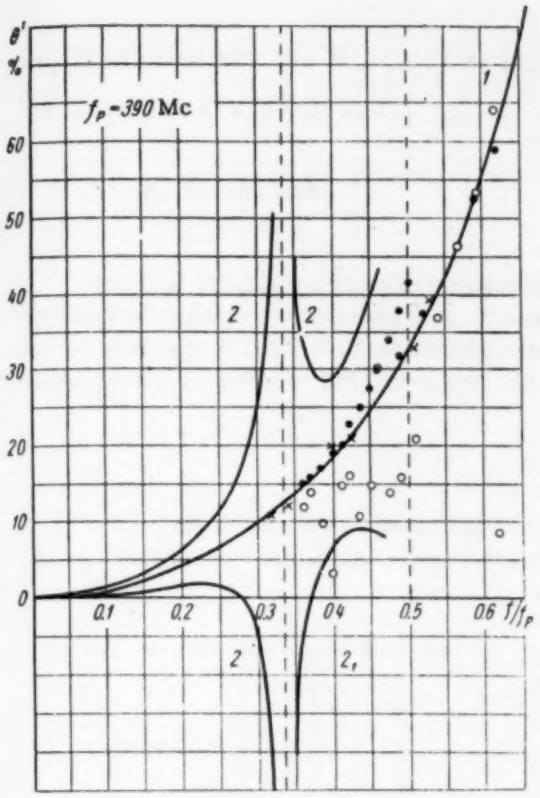

Fig. 5. Resonance error of voltmeter VKS-7.

1) $\theta_1 = \frac{\left(\frac{f}{f_p}\right)^2}{1-\left(\frac{f}{f_p}\right)^2} 100\%$; 2) $\theta_{2,3}$ with 3% of the second and 3% of the third harmonic present in the signal; ○) experimental points with the presence of harmonics in the signal; ● ×) experimental points with a filtered signal from different oscillators.

For an experimental confirmation of the effect of harmonics on the value of the resonance error, the latter was determined for voltmeter VKS-7 by comparing its readings at different frequencies with a signal purely sinusoidal and distorted by harmonics with those of a high-frequency compensation-type VNIIM voltmeter, which had a higher resonance frequency of 2,100 Mc. This method of determining the resonance error was used by many authors and is based on the property of a voltmeter with a higher resonant frequency giving smaller errors than the one with a lower frequency. The quantitative relationship of harmonics and their phase distribution were random and unknown. The resonance errors thus obtained are given in Fig. 5. On the same graph a calculated resonance error due to a 3% second harmonic and 3% third harmonic content was also plotted. The latter two curves were calculated from (7) for the case when the maximum value of the fundamental and the harmonic across the anode-cathode circuit are in phase and in anti-phase.

It will be seen from Fig. 5 that with a sinusoidal waveform the experimental points agree well with the calculated ones. When harmonics are present in the signal, however, the experimental points differ considerably from the calculated ones, which confirms the effect of the harmonics on the value of the resonance error of diode peak voltmeters.

CONCLUSIONS

1. The error in voltage measurement by means of diode voltmeters due to the distortion of the waveform can be several times greater at high frequencies than at low ones.

2. When voltages are measured at frequencies close to the value of:

$$f = \frac{f_p}{n}. \qquad (9)$$

there can be considerable additional resonance errors due to the presence of harmonics in the voltage under test.

3. In order to account for this error it is necessary to have quantitative and phase data on the harmonics in the signal under test, which are not always available. Hence, when measuring voltages by means of diode peak voltmeters, and especially when determining experimentally the resonance error characteristic of these voltmeters, it is advisable not to choose frequencies (if that is possible) close to the value given in Formula (9). The question of a compulsory indication of the resonance frequency in the technical specifications of voltmeters should be raised.

4. When the resonance error curve is determined experimentally it is advisable to set particularly high requirements for the auxiliary oscillator voltage waveform and to take steps to reduce the content of each harmonic (and especially those of a higher order) to 0.1 to 0.2%.

5. Diode voltmeters used in standard signal generators and power meters at frequencies for which the resonance error becomes important, can produce errors several times greater than the nonlinear distortion coefficient. This fact must be taken into consideration when standard signal generators are developed.

VISCOSITY MEASUREMENTS

ON THE THEORY OF VISCOSIMETERS FOR THE DETERMINATION OF RELATIVE VISCOSITY

A. D. Al'tshul'

The type VU (Engler) viscosimeter consists of a cylindrical vessel (Fig. 1) with a spherical bottom and a capillary of standard size attached to it. Viscosity in VU (° E) degrees is the ratio between the time T required for the discharge of 200 cm^3 of the tested liquid at testing temperature and the number T_0 for water (time required for the discharge of 200 cm^3 of distilled water at a temperature of 20° C); i.e.,

$$^{\circ}BY = \frac{T}{T_0}. \tag{1}$$

In conversion from VU degrees to kinematic viscosity, difficulties arise, which are connected with the fact that the theoretical formulas (by Mises, Schiller, et al.), which have been offered until the present time, do not agree well enough with experimental data [1]. In connection with this, the empirical formulas by Ubellode and Vogel [2] have been used for the conversion of VU degrees into kinematic viscosity.* Meanwhile, the investigations in the field of discharge of viscous liquids [3, 4, 5], which were performed during the last few years, make it possible to propose a theory of type VU viscosimeters which is sufficiently well substantiated by the available experimental data.

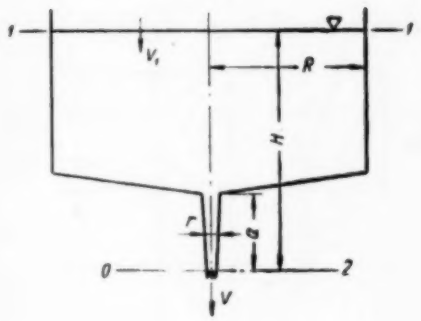

Fig. 1

Let us find the relation between the liquid discharge time t from the viscosimeter and kinematic viscosity of the liquid ν.** Denote the cross-sectional radius of the vessel by R, the capillary radius by r, the height of the liquid level above the outlet section of the capillary by H, and the average velocity in the capillary by V. Then, the discharge equation can be written in the form

$$-\pi R^2 \frac{dH}{dt} = \pi r^2 V. \tag{2}$$

We shall determine the velocity V by writing Bernoulli's equation for two sections: one at the liquid surface in the vessel (section 1) and second, after the liquid left the viscosimeter nozzle (section 2):

$$H + \frac{\alpha_1 V_1^2}{2g} = \frac{\alpha V^2}{2g} + h_{\text{loss}}^{1-2}, \tag{3}$$

* A table for the conversion of kinematic viscosity into relative viscosity composed on the basis of processing of experimental data obtained by the B. I. Mendeleev VNIIM has been accepted in the USSR (Appendix 2 to the All-Union Government standard 33-53).

** G. S. Al'tovskii took part in the calculations.

where V_1 is the flow velocity in the viscosimeter cylinder, and
V is the discharge velocity of the liquid from the discharge nozzle.

The pressure losses along the path from section 1) to section 2) are composed of the pressure loss h_{fr} due to friction along the discharge nozzle and the pressure loss h_{en} at the entrance to the discharge nozzle. The pressure loss due to friction along the length of the discharge nozzle is found according to Poiseuille's equation:

$$h_{fr} = \frac{8\nu a}{g r^2} V. \tag{4}$$

In order to determine the pressure loss at the entrance to the discharge nozzle, we shall use Wuest's equation [5], which he obtained theoretically in 1954 and which is valid for the motion of liquids with small Reynolds numbers:

$$\Delta P = 50{,}4\frac{Q\nu\varrho}{\pi d^3}. \tag{5}$$

Equation (5) can be also represented in the form

$$h_{in} = \frac{\Delta P}{\gamma} = 6.3\frac{\nu}{gr} V. \tag{6}$$

Substituting (4) and (6) in (3) and neglecting (as a small quantity) the term $\frac{\alpha_1 V_1^2}{2g}$, we obtain:

$$H = \frac{\alpha V^2}{2g} + \frac{8\nu a}{g r^2} V + \frac{6.3\nu}{gr} V. \tag{7}$$

Solving this equation for V, we obtain:

$$V = -\frac{\nu}{\alpha r}\left(8\frac{a}{r} + 6.3\right) + \frac{1}{\alpha r}\sqrt{\nu^2\left(8\frac{a}{r} + 6.3\right)^2 + 2g\alpha H r^2}. \tag{8}$$

Substituting (8) in (2), we obtain (after simple transformations):

$$\frac{dH}{dt} = \frac{r\nu}{R^2\alpha}\left(8\frac{a}{r} + 6.3\right) \times \left[1 - \sqrt{1 + KH}\right]. \tag{9}$$

where K denotes

$$\frac{2g\alpha r^2}{\nu^2\left(8\frac{a}{r} + 6.3\right)^2}. \tag{10}$$

Integrating (9), we find the time T necessary for the liquid level in the vessel to descend from height h_0 to height h:

$$T = \frac{R^2\nu\left(8\frac{a}{r} + 6.3\right)}{gr^3}\left[\ln\frac{C_0 - 1}{C_1 - 1} + C_0 - C_1\right]. \tag{11}$$

where

$$C_0=\sqrt{1+Kh_0} \text{ and } C_1=\sqrt{1+Kh_1} \tag{12}$$

The dimensions of the type VU viscosimeter are standard and they are given by the following data: r_{ave} = = 0.1425 cm, R = 5.3 cm, a = 2 cm, h_0 = 5.2 cm, and h_1 = 2.93 cm. Substituting these numerical values in the foregoing equations, assuming T_0 = 51.6 sec [6] and considering that laminar flow (Coriolis' coefficient α = 2) takes place in all cases of discharge from the type VU viscosimeter, we obtain:

$$K=\frac{0.00568}{\nu^2},$$

$$C_0=\sqrt{1+\frac{0.0294}{\nu^2}}, \tag{13}$$

$$C_1=\sqrt{1+\frac{0.0166}{\nu^2}}$$

Substituting the values found for K, C_0, and C_1, in (11), and taking into account (1), we obtain:

$$^{\circ}BY=24\left[2.3\lg\frac{\sqrt{\nu^2+0.0294}-\nu}{\sqrt{\nu^2+0.0166}-\nu}+\right.$$
$$\left.+\frac{1}{\nu}\left(\sqrt{\nu^2+0.0294}-\sqrt{\nu^2+0.0166}\right)\right]\nu, \tag{14}$$

which is the sought dependence between degrees VU (° E) and ν.

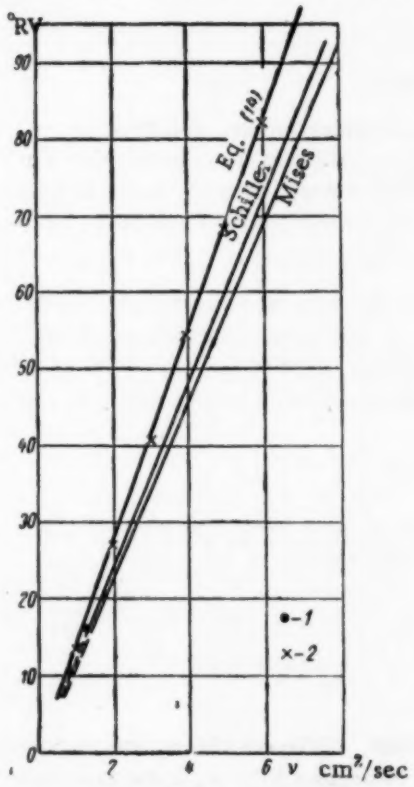

Fig. 2. 1) According to VNIIM experiments; 2) according to the Ubellode equation.

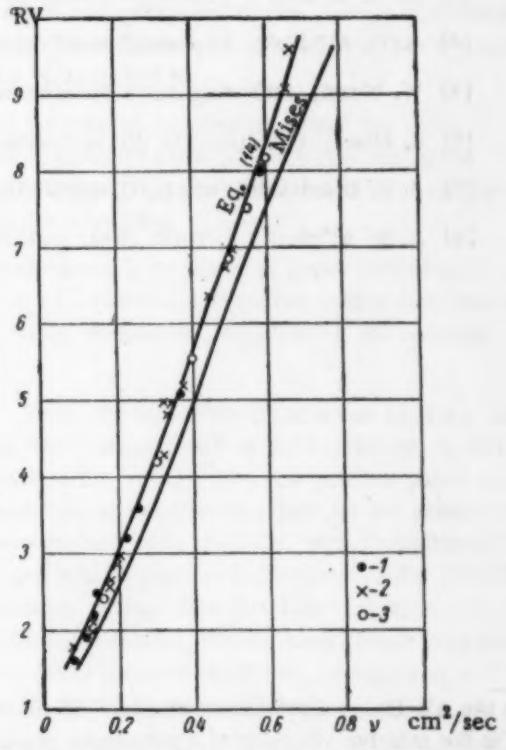

Fig. 3. 1) According to VNIIM experiments; 2) according to data by Frank, Erk, et al.; 3) according to the Ubellode equation.

Figure 2 shows the $\nu = f(^{\circ}E)$ curves plotted according to theoretical formulas by Mises and Schiller and the proposed Eq. (14). Here are given the results of calculations according to the empirical Ubellode equation, obtained on the basis of generalization of the most reliable experimental data. It is obvious from the graph that the Ubellode curve practically coincides with (14), but deviates considerably from curves corresponding to equations by Mises and Schiller. Figure 3 shows a comparison of the obtained Eq. (14) with the Ubellode equation and experimental data obtained by Frank and Erk [1] for values of viscosity $\nu < 1$ cm^2/sec. We can see that also here, Eq. (14) agrees very well with experimental data.

Mises [6] and Schiller did not take into account the pressure losses at the entrance to the discharge nozzle, considering them as negligeable when they derived their equations. It can be seen from the given investigation that such a neglect of pressure losses at the entrance to the discharge nozzle leads to a substantial deviation of obtained equations from experimental data. The successful coincidence of the theoretical Eq. (14) with experimental data can be considered also as a confirmation of Eq. (5), obtained theoretically by Wuest, which shows a good correspondence with experiments also in other cases [8].

For a viscosity of $\nu > 0.5$ cm^2/sec, the curve of Eq. (14) is very close to a straight line (the term in square brackets becomes practically a constant quantity). Therefore, for approximate calculations in measuring liquids of considerable viscosity, it is possible to use the relation

$$^{\circ}BY = 13.67\ \nu, \tag{15}$$

which also follows from the Ubellode equation.*

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* In the All-Union Government standard 33-53 (Appendix 2) the relation $VU_t = 0.135\ \nu_t$ was proposed, where VU_t is the relative viscosity of a petroleum product at temperature t in degrees VU; ν_t is the kinematic viscosity of the petroleum product at the temperature t (in cm^3).

APPARATUS FOR AUTOMATIC DETERMINATION OF VISCOSITY OF NONTRANSPARENT LIQUIDS

A. I. Andrievskii, N. N. Karelin, and Iu. G. Iuskevich

The most widely used method of measuring the viscosity of liquids yielding reliable results is the Stokes absolute method based on measuring the falling velocity of hard spheres in the investigated liquid. This method can also be used for nontransparent liquids, but in the given case, for fixing the position of the sphere at a certain spot in the tube filled with the investigated liquid, the induction method with the application of ferromagnetic spheres [1, 2, 3] is used.

Such an apparatus consists of two identical coils with two windings (Fig. 1). The outside windings K_1 are connected in series and connected to the secondary winding of a step-down transformer. The inner windings K_2, occupying a small portion of the length, are also connected in series, but, unlike the outside windings, in opposition to each other, so that the currents induced in them would compensate each other. If the compensation of induced currents in internal coils is disturbed when ferromagnetic spheres pass through the upper or the lower coil, a certain emf will be generated.

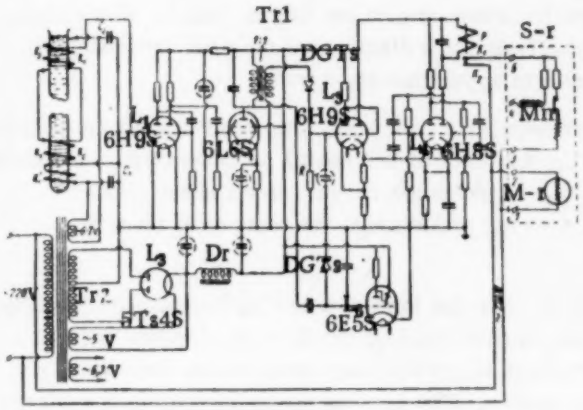

Fig. 1

As an indicator registering the passage of the ferromagnetic sphere through the upper or the lower coil, a vibration galvanometer or an electron optical indicator of the "magic eye" type can be used (for instance, the 6E5 S tube). In the last case, the small emf generated by the passage of spheres through the coils must be amplified to a magnitude of the order of 6-8 v.

For a more accurate determination of the time required for the passage of spheres through the coils, elimination of visual errors in observation and convenience in work, a circuit automatically registering the motion time of spheres between certain positions of the coils can be used. The schematic diagram of such an apparatus is given in Fig. 1. Figure 2 shows the block diagram of the apparatus.

The emf generated by the passage of the ferromagnetic sphere through the upper or lower coil of unit 1, is amplified by an amplitude amplifier 2, constructed in the form of a two-stage amplifier with a dual triode, and is fed to the power amplifier 3, to whose anode circuit the output transformer, eliminating the constant component of the amplified alternating voltage, is connected.

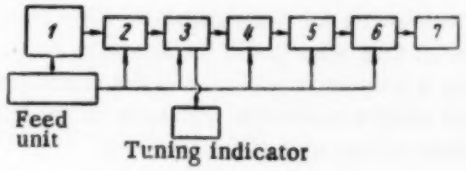

Fig. 2

From the secondary transformer winding, the amplified voltage is fed to the modulator 4, which transforms the voltage into flat positive pulses equal, in duration, to the time required for the passage of spheres through separate coils, whose amplitude is the envelope of positive half-waves of the amplified alternating voltage (see the time diagram in Fig. 3). For the demodulator, the simplest circuit consisting of the DGTs germanium diode, resistance R_1 and capacitance C_1 is used.

The discriminator 5, consisting of the dual triode L_3 is connected galvanically to the demodulator. The purpose of the discriminator is two-fold: on one hand, it generates output pulses with sharp built-up fronts which are necessary for triggering the dual stability trigger circuit 6 (of the twin counter with the L_4 tube); on the

other hand, having a determined operation threshold (its amplitude changes by jumps every time when the changing input signal passes through a certain determined value), it secures the operation of the trigger circuit and the connection or disconnection of the seconds counter 7) for completely defined positions of spheres in the coils, depending on their size and the feeding voltage of outside coils. The intensity of the signal necessary for the discriminator in the 6N9S tube (bias threshold) can be regulated by resistance R_2, which yields for a value equal to 5.1 kohm, a voltage of approximately 3.5 v.

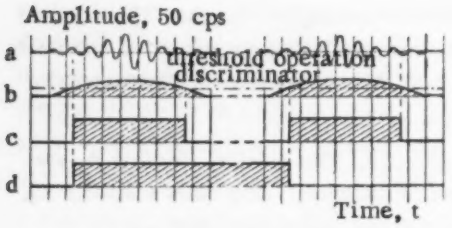

Fig. 3. a) Amplifier; b) demodulator; c) discriminator; d) trigger circuit and the operation time of the seconds counter.

It follows from the time diagram (Fig. 3) that the trigger circuit (frequency divider and the twin counter) is switched from one state into another by the positive fronts of trigger pulses which are tapped off the discriminator; before the pulses are supplied, the trigger circuit can stay indefinitely in either of the two stable states (depending upon the preceding sequence of events). An electromagnetic relay, connecting or disconnecting the electric seconds counter when the corresponding pulses are supplied, is connected to the anode load of the right-hand-side arm of the trigger circuit. The circuit operates positively for a diameter of the steel ferromagnetic spheres equal to approximately 3 mm.

The anode loads in the trigger arms are somewhat asymmetrical; the load, into whose circuit the additional resistance of the coil winding of the electromagnetic relay (of the order of 2-3 kohm) is connected, is somewhat greater than the load of the left-hand triode of the L_4 tube, due to which the trigger circuit is established in a position where the right-hand triode is blocked (the current does not pass through the relay coil) when the apparatus is connected to the power supply.

The device has an additional compensation coil K_1' (Fig. 1) in the form of a few additional wire windings wound on a small frame, which when moved along one of the outside windings provides the required current compensation in coils. For the establishment of initial compensation, an electron-beam tuning indicator L_6 consisting of the 6E5S tube is introduced in the circuit of the device. The best initial compensation is achieved for a maximum spacing of the shadow sector of the tube.

In order to protect the amplifier from interference from the electrical network, the outside windings of the instrument coils are blocked against high frequency by the condensers C_2 and C_3.

As an electric seconds counter, a timing device consisting of a motor, magnetic clutch, and a measuring mechanism can be used, permitting the measurement of duration of any mechanical process with an accuracy up to 0.01 sec.

For the circuit feed, any power transformer (for instance, the ELS-2) providing an anode voltage of the order of 250 v can be used. The circuit uses very little current and the choke in the rectifier filter can be replaced by a resistor. It should also be noted that the heating voltage can be simultaneously used for the feed of outside windings of the unit fixing the position of the spheres.

The testing of the instrument constructed on the basis of the developed circuit and also its application in laboratory work showed that the discrepancies of individual measurements of time required for the passage of the sphere, i.e., of the time interval between two consecutive moments of the relay operation when the sphere passed through the coils, did not exceed 0.01 sec, and, consequently, they were inside the accuracy limits of the electric seconds counter used in the given instrument. Therefore, a possible dependence of the moment of relay operation on the intensity of voltage fed to the apparatus does not exert a substantial influence on the measurement accuracy of the instrument, and, thus, the introduction of feed stabilization is not required.

In view of the possibility of using spheres of relatively small diameter, the influence of the walls of the tube filled with the investigated liquid is negligible, which is of primary importance in the case of absolute measurements of viscosity. In connection with this, one of the advantages of the given apparatus should be noted, in comparison, for instance, with the apparatus described in [2], where spheres of a diameter of the order of 10 mm made of special material are proposed; while in the given arrangement, steel spheres from ball-bearings can be used.

SUMMARY

The described circuit provides a simplification and automatization of the process of viscosity measurement according to Stokes' method, with a considerably increased measurement accuracy. It can be recommended for measurements of viscosity of a hundreth to several hundreths of a poise. For an investigation of the dependence of viscosity on temperature, the glass tube may be heated by any known method.

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MERCURY ILLUMINATOR IN REFRACTOMETRY

A. A. Zaika, V. I. Litvak, and N. Ia. Epshtein

One of the most widespread methods of quantitative analysis of solutions in laboratory practice is the refractometry method based on the application of the dependence of the refraction index of the investigated solution on the amount of so-called dry substance contained in it. Here, the index of refraction for the same investigated substance has various values depending upon the wavelength of monochromatic light in which the measurement is performed.

The basis of the scale graduation of the overwhelming majority of refractometers is the dependence of the content of dry substances on n_D (the index of refraction for the spectral line D of sodium) ($\lambda = 589.3$ m μ).

For an increase of the method accuracy, it is convenient, in a number of cases, to graduate the refractometer scale according to n_h, the index of refraction for the h ($\lambda = 404.6$ mμ) spectral line of mercury; as with a decrease of the wavelength of monochromatic light, the variation in indices of refraction increases, corresponding to the same change in concentration of the investigated solution.

Content of dry substances in %	n_h	Content of dry substances in %	n_h	Content of dry substances in %	n_h
0.0	1.3424	18.5	1.3709	37.0	1.4035
0.5	1.3431	19.0	1.3717	37.5	1.4044
1.0	1.3438	19.5	1.3724	38.0	1.4053
1.5	1.3446	20.0	1.3732	38.5	1.4063
2.0	1.3453	20.5	1.3741	39.0	1.4073
2.5	1.3461	21.0	1.3750	39.5	1.4083
3.0	1.3468	21.5	1.3759	40.0	1.4093
3.5	1.3476	22.0	1.3768	40.5	1.4103
4.0	1.3484	22.5	1.3777	41.0	1.4113
4.5	1.3491	23.0	1.3786	41.5	1.4122
5.0	1.3498	23.5	1.3795	42.0	1.4132
5.5	1.3506	24.0	1.3804	42.5	1.4142
6.0	1.3514	24.5	1.3813	43.0	1.4151
6.5	1.3522	25.0	1.3822	43.5	1.4160
7.0	1.3529	25.5	1.3831	44.0	1.4170
7.5	1.3536	26.0	1.3840	44.5	1.4181
8.0	1.3544	26.5	1.3849	45.0	1.4191
8.5	1.3552	27.0	1.3857	45.5	1.4202
9.0	1.3560	27.5	1.3865	46.0	1.4213
9.5	1.3567	28.0	1.3874	46.5	1.4223
10.0	1.3574	28.5	1.3882	47.0	1.4234
10.5	1.3582	29.0	1.3890	47.5	1.4246
11.0	1.3589	29.5	1.3899	48.0	1.4257
11.5	1.3597	30.0	1.3907	48.5	1.4268
12.0	1.3606	30.5	1.3916	49.0	1.4280
12.5	1.3614	31.0	1.3924	49.5	1.4291
13.0	1.3621	31.5	1.3933	50.0	1.4304
13.5	1.3629	32.0	1.3943	50.5	1.4315
14.0	1.3636	32.5	1.3952	51.0	1.4329
14.5	1.3645	33.0	1.3961	51.5	1.4341
15.0	1.3653	33.5	1.3971	52.0	1.4353
15.5	1.3661	34.0	1.3980	52.5	1.4366
16.0	1.3669	34.5	1.3989	53.0	1.4377
16.5	1.3676	35.0	1.3998	53.5	1.4390
17.0	1.3684	35.5	1.4007	54.0	1.4401
17.5	1.3692	36.0	1.4016	54.5	1.4413
18.0	1.3701	36.5	1.4025	55.0	1.4425

In the TsKB of the Kiev Sovnarkhoz, a construction of an indicating and regulating automatic refractometer was developed. As a light source, it uses a mercury lamp in a quartz bulb with a light filter for the mercury h line. This gave the possibility for the given concentration range of solutions to obtain a more widely spread scale than by using, for instance, a sodium lamp.

The authors established experimentally the dependence of n_h on the solution concentration, which was necessary for the graduation of the refractometer scale.

The method of performing the work consisted of the following. By means of the Pul'frikh refractometer, the limiting angles of departure of the beam from the system consisting of the investigated solution of saccharose and the refractometer prism were measured with an accuracy to 1 minute. Such measurements were performed for solutions with a saccharose concentration from 0 to 55%.

The index of refraction n_h of the investigated solution in dependence on the limiting angle of departure i_h of the beam was determined according to the equation

$$n_h = \sqrt{N_h - \sin^2 i_h},$$

where N_h is the index of refraction of the Pul'frikh refractometer prism for the mercury h line.

As a light source, the PRK-4 mercury lamp was applied. The content of dry substances was determined by a Zeiss laboratory refractometer with an accuracy of up to 0.1% of dry substances. The measurements were performed at a constant temperature of 20 ± 0.05° C. The temperature was kept constant by means of a thermostat.

A table of the dependences of the index of refraction n_h on the dry substances content (saccharose), composed on the basis of experimental data, is given above. A control check showed that the errors in refractometric determination of the solution concentration when the table is used does not exceed ± 0.3% of dry substances. The accuracy of the given table is entirely sufficient for the graduation of the automatic refractometer scale whose scale division is equal to 1% of dry substances (by saccharose).

CONCERNING THE NEW NATIONAL SOVIET STANDARD "THE UNIT OF X- AND γ-RADIATION AND RADIOACTIVITY"

M. F. Iudin

In July, 1958, the Committee of Standards on Measures and Measuring Devices established a new NSS 8848-58, "The Unit of X- and γ-Radiation and Radioactivity" to be put into effect on January 1, 1959.*

The new NSS replaces the standards that have been in effect since 1934, NS VKS 7159, "Unit of Radioactivity" and NS VKS 7623 "Unit of X-ray Radiation." With the introduction of the new standard on January 1, 1959 the NS 5159 "Unit of Radium" is also replaced.

The establishment of the new NSS was preceded by a great deal of preparatory work carried on from 1953 to 1958. The initial version of the NSS project was worked out by a committee organized by the D. I. Mendeleev All-Union Scientific and Research Metrological Institute and it was sent for review to all institutes, foundations, divisions and individual specialists in the given field of measurement. During the development of the NSS the recommendations of the International Committee on Radiological Units and Measurements, ICRM, [1] were followed, also in the last few years many discussions took place regarding individual concepts, the determination of physical magnitudes, and the units to be used in these determinations in the field of ionizing radiation [2-10].

It had already long ago become necessary to re-examine the old standard on the units of x-ray radiation and radioactivity (established in 1934). At the time that these standards were developed the dosage was fixed only with regard to x-ray radiation in which the energy quanta did not exceed 200 to 300 kev, and for only one radioactive isotope – radium and its disintegration (or decay) products. For the last 20 years, and even longer, the science of roentgonometry and radiometry has been greatly developed. Due to the successes in the field of charged particle acceleration, and especially to the mastery of atomic energy, it has become possible to obtain and make use of electromagnetic radiation with energy quanta of up to tens of millions of electron-volts and consisting of many radioactive isotopes.

In the new standard, units are cited for the ionizing radiation that is most often used in present-day dosage. The units are determined in terms of the MKS (meter, kilogram, second) and CGS (cm, gram, second) systems, the first place being accorded to the determination in terms of the MKS units, since this system is recommended in the USSR as the preferred system. The units are also determined in terms of the CGS system because of the fact that at the present time the dosages of ionizing radiation are stated in terms of the CGS system, since the sizes and values of the magnitudes to be measured are extremely small and it is more convenient in practice to express them in terms of cm and grams.

In connection with the tempestuous development, up to the present time, of this branch of measurement there is unfortunately, at the present time, no fixed and uniform terminology (accepted by all). It is possible at the present time to count up to forty different definitions (or determinations) connected with various understandings of the doses and the units for their measurement. For this reason, it is especially necessary to determine, in the first place, in the standard the physical magnitude of the unit called the roentgen.

* K. K. Aglintsev, M. F. Karavaev, and M. F. Iudin took part in the development of the standard.

Even as far back as 1913, Christian [11] proposed that there be a precise physical understanding of the dose that was represented by the unit known as the roentgen. It was proposed that the dose be understood to be equal to the amount of radiation energy absorbed by some element of a body divided by the volume of that element. However, due to the fact that it was impossible to measure this dose directly, this proposal could not be used to create a basis for dosimetry (radiation monitoring). Today, as in 1913, there are no devices available which could be used to measure the amount of energy in the electromagnetic radiation in the cases of practical interest. For this reason we are even now forced to determine the amount of energy that is absorbed by indirect methods – by recount.

In the NS on "Units of X-Ray Radiation" in force at present the dose was considered to consist of the x-ray energy delivered to a unit volume of the irradiated medium.

In the first international recommendations, 1928, the roentgen was established as the unit of "x-ray radiation." In the recommendation of 1937 the application of the roentgen was expanded to include γ-radiation, and it was stated that the roentgen was "the unit quantity or dose of x- or γ-radiation." The term "quantity of radiation" was identified with the term "dose".

In the recommendation of the ICRM, made in 1950, the physical magnitude of the unit which was to be considered as the roentgen was changed; however, the name and the size were preserved. It was proposed that energy absorbed by the air be referred to the unit of irradiated volume rather that to the mass of air contained under normal conditions in a unit volume (0.001293 g). From the physical point of view such a change was expedient because during the use of a high-energy radiator it is difficult to determine the volume boundaries of the body being irradiated; it is easier to establish the mass of the material that is being subjected to radiation.

In the recommendations made by the ICRM in 1953 the unit of which the physical magnitude is called the roentgen is still not clear. On the one hand, the roentgen is treated as a unit of dosage, in spite of the fact that a clear determination of this term has not been made; on the other hand, the roentgen is considered the unit of radiation energy falling upon 1 cm^2.

The 1956 recommendations of the ICRM propose that the roentgen be defined as the unit dose of irradiation (exposure dose). The irradiation dose of the exposure dose of x- or γ-radiation at a point in the radiation field is treated as a measure of the irradiation, based upon the ability of the radiation to produce ionization.

Out of the many existing definitions of the dose it was necessary to select one definition for use in the NSS.

The roentgen is established as the unit dose of x- and γ-radiation. In view of the fact that up to the present time, as mentioned above, there is no definitely established terminology, a footnote has been added in the standard giving the determination of the dose. The dose of x- or γ-radiation is a measure of the amount of radiation based upon its ionizing properties. In this manner, in the new standard, we associate with the term dose a physical value that differs in physical magnitude from the dosage that is defined in the present standard as the unit of x-ray radiation. Previously, the dose was defined as the amount of radiation energy absorbed by a unit volume (mass). Now, according to the new NSS, the definition of the dose as a measure of radiation is based upon the ability of the radiation to produce ionization. This agrees with the definition of the dose or irradiation (exposure dose – in English, dose d'exposition – in French, Bestrahlungsdosis – in German) recommended by the ICRM in 1956. Therefore, in accordance with the new NSS, the dose must conform to the characteristic radiation fields of x- or γ-radiation and must be measured in roentgens.

The power unit of the dose is established by the NSS as the roentgen per second (r/sec). This unit may also be used to determine the radiation field and characteristics of the various sources of x-rays and γ-rays.

In contrast with the standard now in effect the new standard, in accordance with the international recommendations, introduces a new term "absorbed dose of radiation," by which we mean the absorbed energy of the ionizing radiation with respect to the unit mass of the irradiated substance or object.

The absorbed dose includes all the energy that is absorbed by the unit mass of any substance that is being examined, i.e., it includes as energy that has been transmitted to the irradiated object, the energy due to nuclear collisions as well as the energy due to electron collisions. Therefore, the new term "absorbed dose of radiation" corresponds to the old understanding of the meaning of the term dose. This has been done in order to exclude the possibility of considering the value of the dose, which has been measured in roentgens by a roentgenometer, as the dose that is absorbed by the tissues. The standard establishes the rad as the unit to be used in the measurement

of the absorbed dose, the rad is equal to 0.01 joule per kilogram of irradiated substance or 100 ergs per gram of irradiated substance.

As a result of the fact that the rad, while measuring the absorbed dose, in no way characterizes the medium, it becomes necessary to indicate the medium. For example, the term "tissue rad" is often used. By this designation we mean the radiation energy that has been absorbed by the soft human tissue as calculated per unit mass of such tissue.

It is necessary to underline once again the difference between the terms "dose" and "absorbed dose" as defined in the new standard. The term dose characterizes the radiation which is to be used in some manner, either to irradiate some biological objects or to investigate a reaction taking place under the influence of the radiation. This magnitude is measured by the sum of the charges of the ions ΔQ of any sign, created in the air by electrons, that originate due to the x- or γ-radiation in a small mass Δm of air, divided by this mass of air. The roentgen is the unit that is used in measuring the dose. In accordance with the definition of the roentgen, a dose of the magnitude of one roentgen will occur at that point of the radiation field in which the electrons created in a mass of 1 cm^3 of dry atmosphere will produce along their paths ions of any sign with a total charge equal to a unit charge in the CGS system. In the MKS system this corresponds to $0.258 \cdot 10^{-3}$ amp·sec/kg.

The absorbed dose will be determined as the radiation field which is used to irradiate also the constituents of the irradiated object.

Unfortunately, the absorbed dose cannot be measured directly with the necessary accuracy with the presently existing measurement techniques. This is due to the fact that the total absorbed energy is usually too small, and also because it is in general impossible to measure it in the portions of the body that are of interest.

The absorbed dose is usually computed from the dose. In order to do this we use an ionization camera, constructed so as to satisfy Bragg-Gray theory. In accordance with this theory the relationship shown below holds between the energy E_m transmitted to a unit mass of a solid body and the ionization I_m, computed per unit mass of a gaseous cavity in the body:

$$E_m = I_m \varepsilon S,$$

where ϵ is the mean work of ionization, i.e., the mean energy expended by the ionizing particles during the production of one pair of ions in the gas, and

S represents the stopping power of the material of which the walls of the ionization chamber are constructed and of the gas which fills the chamber.

At the present time, for x-rays and γ-rays with energy quanta of 20 thousand electron-volts or higher, the recommended most probable value for ϵ is 34 electron-volts.

It is obvious that the biological effect of the ionizing radiation is more closely connected with the absorbed dose than with the dose.

In order to obtain the correct measurement of the dose in roentgens, it is necessary that certain conditions be fulfilled, and in particular, the condition of electronic equilibrium. During electronic equilibrium the ionization that is produced in a small mass Δm of the object being investigated by means of the electrons created by irradiating the interior of the mass is compensated by the ionization of the interior of the mass Δm by the electrons created in the interior of this mass.

In view of the fact that in practice it is extremely difficult to fulfill the conditions of electronic equilibrium while determining the dose in roentgens when the energy of the quanta that compose the radiation is very high, it is specified in a footnote of the NSS that the use of the roentgen as a unit for the measurement of the dose may be permitted in the measurement of radiation with energy quanta of up to three million electron-volts (Mev).

To characterize the activity of radioactive isotopes the standard establishes a unit called the curie. In contrast to the recommendations of the ICRM, in which it is suggested that the curie be defined as the unit quantity of a radioactive substance appraised in accordance with its radioactivity, the NSS defines the curie as the unit to be used in measuring the activity of radioactive isotopes as determined by the number of nuclei that disintegrate in one second. This, undoubtedly a more rational determination of the magnitude of the activity, has

been introduced into the USSR by K. K. Aglintsev [12]. As a matter of fact, if we consider one curie of radium as corresponding to a one-gram mass of radium then if we take one curie of Co^{60} it will correspond to 0.87 milligram of Co; but if we take 1 curie of Pu^{239} it will correspond to a mass of Pu of approximately 16 grams.

In view of the differences between the NSS and the international recommendations a note has been added in the appendix of the standard giving a literal translation of the accepted definition of the curie as stated in the ICRM text.

In connection with the fact that in the Soviet Union, until very recently, only radium preparations were used as standards for the measurement of γ-radiation, and then, simultaneously, other radioactive preparations were placed into widespread use as standard sources of γ-radiation, it was necessary to appraise the strength of the γ-radiation of the various preparations by the use of the γ-radiation of radium. In order to satisfy the practical inquiries of many organizations the value of the "radium γ-equivalent of the preparation" has been shown in the standard. The standard establishes the milligram-equivalent of radium (mgm-equiv. radium) as the unit to be used in determining this value.

It is clear, that, with the passage of time, when various source preparations of the various γ-radiators will be created and will receive widespread use, the need for the use of this unit will fall off. The γ-radiation of a given isotope will then be compared with the γ-radiation of a standard preparation of the same isotope.

In order to measure the intensity of the radiation field the NSS has established a unit which is defined in the MKS system in watts/m^2 and in the CGS system in ergs/sec $\cdot$ cm^2.

Unfortunately, the last two units of the standard, the milligram-equivalent of radium and the erg/sec $\cdot$ cm^2, have not been given proper names. This will, without doubt, introduce some inconvenience.

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METHODS AND EQUIPMENT FOR CALIBRATION AND CHECKING OF ACCELEROMETERS

S. S. Shchedrovitskii

The characteristic features of the contemporary stage in development of the equipment for measuring accelerations (accelerometers) are:

a broadening of the measurement range with respect to the magnitude of accelerations,as well as with respect to the frequency range;

a broadening of the scope of application of accelerometers,and, in particular, their use for the quality control of machines (machine tools, pumps, motors, etc.) and data transmitters of the automatic pilot instruments.

These circumstances brought about the necessity of perfecting the existing, and the development of new, means for graduation and checking of instruments for measurement of acceleration, where the new fields of accelerometer application necessitated the solution of the problem of securing not only the reproducibility but also the accuracy of measurement results, i.e., the reduction with a required accuracy of their readings to the accepted units.

A great number of types and constructions of the equipment for calibration and checking of accelerometers are available. This equipment can be subdivided into devices for static and dynamic calibration. Devices by means of which the calibration of accelerometers under static, as well as dynamic, operating conditions is performed, can also find their application.

We can limit ourselves to static calibration in those cases where the accelerometers are designated for measurement of quantities constant in time or accelerations which change very slowly. The methods of static graduation of accelerometers which are being applied at the present time are shown in Table 1.

A disadvantage of the method of calibrating accelerometers by means of changing the slope angle of the sensitivity axis is the limited range of acceleration measurements; its advantage is a high accuracy secured by the application of the corresponding means for angle measurements.

The method of calibration based on the application of loads to the sensitive element of the accelerometer requires the determination of the mass value of the inertial weight m_0. This can be achieved either by means of calculating the magnitude of the reduced mass of the load (by taking into account the mass of springs and other moveable elements), or by means of the experimental determination of the output signal corresponding to a change in acceleration by g or $2g$ (by the method of changing the slope angle of the instrument),and the selection of the weight giving, for instance, doubled magnitudes of the signal. Both methods of determining m_0 are not free from systematic errors whose magnitudes depend on the accelerometer design. When the accelerometer has a rigorously linear characteristic, the method of load application makes it possible to achieve the calibration with minimum errors.

The method of calibrating accelerometers in a centrifugal field (in a centrifuge) has the disadvantage that for the determination of the acceleration magnitude, it is necessary to know the distance r from the rotation axis to the center of gravity of the inertial weight. The difficulty in determining this distance is aggravated by the fact that it depends on the magnitude of the acting acceleration,and, consequently, is not uniformly determined by placing the device in a centrifuge.

In order to eliminate this error, P. N. Agaletskii [1, 2] proposed the so-called differential method of checking and calibrating accelerometers. According to this method, the instrument is placed first at the distance r_1 from the rotation axis and is examined at the angular velocity ω_1. Then, the instrument is relocated to another distance r_2, and such an angular velocity ω_2 is selected that the output signal is equal to the signal obtained in the first experiment.

TABLE 1

Methods of Reproducing the Acceleration in Static Calibration and Checking of Accelerometers

Method of calibration	Measurement range	Basic relation for the determination of the magnitude of the acting acceleration $\underline{a}$
Change of the slope angle of the sensitivity axes of the accelerometer with respect to the direction of gravity	± 1 g	$a = g \sin \alpha$, where α is the slope angle of the sensitivity axis with respect to the horizon
Application of calibration weights to the sensitive element of the accelerometer	Unlimited	$a = \left(1 + \frac{m}{m_0}\right) g$, where $\underline{m}$ is the mass of the calibration weight, and m_0 is the mass of the inertial weight of the accelerometer.
Rotation of the accelerometer with a constant angular velocity in the horizontal plane about the axis intersecting the sensitivity axis	Theoretically unlimited, practically, ± 250 g	$a = r\omega^2$, where $\underline{r}$ is the distance from the rotation axis to the center of gravity of the inertial weight of the accelerometer, and ω is the angular velocity.

TABLE 2

Generalized Characteristics of Vibrostands for Dynamic Calibration and Checking of Accelerometers

Vibrator type	Limiting values of the vibration amplitude	Reproduction limits of peak acceleration values (in g)	Range of working frequencies (in cps)
Mechanical	± 125 mm	± 30	0- 300
Electrodynamical	± 12 mm	± 50	50-10,000
Resonance	± 2 mm	± 4000	50- 3000
Piezoelectrical	1 μ	± 150	100-20,000

Remark. The quantities given in Table 2 do not represent any given vibrostand, but the totality of known vibrostands of the given operating principle.

In this case, the errors δr in determining r_1 and r_2 will be equal and, consequently,

$$a_1=(r_1+\delta r)\omega_1^2.$$
$$a_2=(r_2+\delta r)\omega_2^2.$$

Since $a_1 = a_2$, we obtain

$$a=\frac{r_1-r_2}{\omega_2^2-\omega_1^2}\omega_1^2\,\omega_2^2.$$

Applying the differential method, it should be borne in mind that simultaneously with the elimination of systematic errors in determining $\underline{r}$, the summation of chance errors due to repeated measurements of $\underline{r}$ and ω takes place.

A positive result is obtained in calibrating and checking by the differential method of such instruments where the location of the center of gravity of the inertial weight cannot be determined with sufficient accuracy by preliminary calculation and the sensitive element effects considerable displacements. In other cases, the measurement of $\underline{r}$ and ω with a sufficient accuracy does not involve difficulties. In the case of small angular velocities, chronometer equipment is used and the duration of a single rotation is determined. Such a system of measuring the angular velocity is achieved in the centrifuge for testing accelerometers, which was developed by the All-Union Scientific Research Institute of the Committee for Standards, Measures, and Measuring Instruments [2].

Under favorable conditions, the errors in graduating accelerometers in this centrifuge amount to ± 0.5%.

Dynamic calibration of accelerometers is necessary in those cases where the instrument is used for the measurement of vibroaccelerations, shock phenomena, and transition processes; its construction does not permit the performance of calibration under static operating conditions and the analytical determination of dynamic errors cannot secure the required accuracy.

In dynamic calibration, either the steady-state harmonic law of the acceleration change in time is reproduced or single impulses, where the acceleration changes as a sinusoid half-wave, are created.

In the first case, the calibration is performed with vibrostands and the criterion of the rate of change of the measured acceleration in time is the frequency of the process, and in the second case, ballistic pendulums or falling hammers are applied and the character of the acceleration change is evaluated by the duration of impulse.

The most important property of the calibration method with harmonic oscillations is the fact that it permits the performance of calibration and checking according to the peak values of acceleration, where indicating instruments are used (the peak values of steady-state vibrations do not change in time), while impulse methods require the application of a recording instrument which introduces dynamic errors. Another great advantage of calibration by means of vibrostands is the simplicity of obtaining frequency characteristics of the instrument, i.e., the dependence between the readings and the frequency of the acceleration variation.

The basic characteristics and the limits of application of various vibrostands for dynamic calibration and testing of accelerometers are given in Table 2.

In the design of vibrostands, all possible precautions are taken which will secure a purely harmonic law of the change of amplitude.

In stands with mechanical vibrators, this is achieved by the application of special kinematic transmissions: lever or cam transmissions. An extension of the construction is used where the stand is made in the form of a weight elastically suspended and the vibrations are induced by the rotation of an unbalanced flywheel.

In the laboratory of the Aircraft Research Center (France) for the calibration of accelerometers in the frequency range of 0.1-20 cps for accelerations of ± 20 g, a mechanical vibrostand is used where the oscillations of the platform are achieved by means of a reducer with elliptical gears [3]; the maximum amplitude is equal to ± 125 mm; the maximum weight of the tested accelerometer is equal to 2 kg and the error in measuring the amplitude does not exceed 0.1 mm.

As can be seen from Table 2, stands with mechanical vibrators are suitable only for the region of low frequencies and small accelerations. Vibrostands with electrodynamic vibrators obtained a very wide application for the calibration of accelerometers for medium ranges of frequencies and accelerations.

An example of stands of this type is the VS300-P vibrostand designed by the D. I. Mendeleev All-Union Scientific Research Institute of Metrology [4].

Fig. 1

The stand (Fig. 1) is designated for operation in the frequency range from 100 to 10,000 cps and a maximum amplitude of 0.5 mm. The platform can be placed at any angle to the horizon within 0-90°. The stand consists of an electrodynamic vibrator, a sound generator of 10,000 cps and a type TU-600 power amplifier. In order to reduce the component oscillations in transverse directions, the mobile system is made in the form of two coils spaced at a distance of more than 0.5 m. The coils are connected by the rod supporting the table. The mobile coils are fed from a generator through an amplifier. A steady magnetic field is created by the immobile excitation coils, which are fed from a constant voltage source of 120 or 240 v. The maximum load on the stand platform is equal to 5 kg; the amplitude of oscillations in transverse directions does not exceed 1% of the amplitude of oscillations in the direction of the working axis of the stand; the nonlinear distortion factor is less than 3%; the error in amplitude measurement is equal to $\pm 1\ \mu$.

Electrodynamic vibrostands for the calibration of accelerometers are applied in TsNIITMASh [4] and many other organizations. In the German Democratic Republic, England, U.S.A., F.R.G., France and a number of other countries, electrodynamic vibrostands for the calibration and testing of vibration equipment are produced in series.

For the attainment of greater acceleration magnitudes and securing a purely harmonic oscillation law at the same time, stands with resonance oscillation exciters are used. Such exciters consist of a beam where the investigated data transmitter is fastened; the vibrations of the beam are maintained at the resonance frequency by means of an electromagnetic, electrodynamic, or other type of vibrator. In one of the stands [7], the beam is clamped in the middle in a cantilever fixed on the armature of the electrodynamic vibrator. The tested data transmitters are fastened at the ends of the beam; their working axes are placed horizontally. The beam is made of drawn aluminum and has a natural frequency of 315 cps. It was used for the calibration of data transmitters for accelerations up to 500 g. For higher accelerations (up to 4000 g) the application of beams of vanadium steel is recommended. A disadvantage of resonance stands is the difficulty in obtaining the frequency characteristics of the instruments. In a number of cases, stands with several beams having various frequencies of free oscillations are applied. Such a stand with eight beams made in the form of tuning forks with natural frequencies of 200, 400, 600, 800, 1000, 1200, 1500, and 3000 cps, has been described in [5]. The errors in determining accelerations by the application of resonance stands has been evaluated as ± 5%.

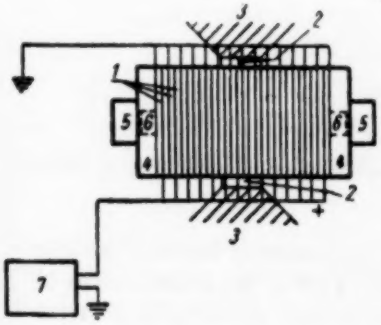

Fig. 2

The necessity for calibrating accelerometers at frequencies over 10,000 cps led to the construction of piezoelectrical vibrators consisting of a set of rings (discs) made of piezoceramic (usually barium titanate) fed from a sinusoidal voltage source through an amplifier. In the vibrator designed by TsNIITMASH [6], forty 35 x 19 mm rings 1 mm thick were applied. Preliminarily polarized rings are connected in a parallel circuit and glued into a pile. To the top surface, a steel ring is cemented, which has a threaded opening for the fastening of accelerometers to be tested. The vibrator base is cemented to a steel stand 140 mm in diameter and 160 mm high. The excitation is effected by means of a sound generator through an amplifier. In the piezoelectric vibrator design (Fig. 2), the pile, consisting of piezoceramic discs 1, is fastened at the joint section 2,

by means of clamp 3. Platforms 4 for the fastening of investigated data transmitters 5 are cemented to the end discs. Control data transmitters 6 are placed inside the platform. The feeding voltage is supplied from the source 7.

TABLE 3

Basic Characteristics of Optical Methods of Measuring the Oscillation Amplitude of Stands for the Calibration of Accelerometers

Denomination of the method	Measurement limits (in μ) lower	upper	Minimum error (in μ)
Observation of the blurred mark image in the form of a:			
a) dash	100	unlimited	± 10
b) highlight	20	500	± 2
c) illuminated slit	10	500	± 1
Observation of the mark with stroboscopical illumination	100	unlimited	± 4
Interference method	0.1	1	± 0.01

The natural frequency of the piezoceramic pile is of the order of 60 kc; the stand constant is $\sim 2 \cdot 10^{-6}$ mm/v and the maximum effective feed voltage is equal to 100 v; the maximum effective acceleration is equal to ~ 0.3 g at a frequency of 1000 cps and ~ 120 g at a frequency of 20,000 cps. Investigations showed that piezoelectrical vibrators facilitate the obtaining of harmonic oscillations in a wide frequency range.

There is no single system of metrological service in the field of acceleration measurement either in the USSR or abroad. Standard accelerometers for direct calibration and testing of operational instruments under dynamic working conditions by the comparison method are not available. Thus, every device assumes the role of a standard one and has to be subjected to tests and certification by the absolute method.

The basis of the absolute method of determining the actual acceleration magnitudes in the certification of vibrostands are the measurements of the amplitude and frequency of vibration displacements and the calculation of the peak acceleration magnitude under the assumption of a purely harmonic steady-state character of oscillations, according to the equation

$$a = \frac{4\pi^2 f^2}{g} A,$$

where a is the acceleration (in g units),

g is the local value of acceleration due to gravity in cm/sec^2,

f is the vibration frequency of the vibrostand in cps, and

A is the oscillation amplitude in cm.

The assumption of the harmonic character of oscillations is the main source of systematic errors, which in the presence of higher harmonics, can attain considerable values.

For the measurement of oscillation frequencies of mechanical vibrostands, frequency meters of various designs are applied. Indicating instruments secure an accuracy of the order of ±1% in the measurement of f. The application of stroboscopic devices fed by standard oscillators and work with fixed values of frequencies make it possible to reduce the errors in measuring f down to 0.1% and less.

For the measurement of the oscillation amplitude of vibrostands, mainly optical methods are used. The basic characteristics of these methods are given in Table 3.

The observation of the blurred image is done by the naked eye for amplitudes of several millimeters and more, and by means of a microscope for smaller amplitudes. For this purpose, microscopes with a magnification of 10x to 400x, provided with a measuring ocular, are used. The lower measuring limit is to a considerable extent determined by the quality of the mark.

For the simultaneous evaluation of the displacement amplitude of the table in lateral directions point marks are used (for instance, highlights on the grains of emery paper).

The readings are facilitated by the fact that in the region of peaks, the motion velocity of the mark is at the minimum and the ends of the blurred image are seen most clearly. Regardless of that, the error in reading the sweep of oscillation is equal to 0.3-0.5 of a division on the ocular scale in the measuring microscope.

In order to increase the reading accuracy, the method of observing the mark by means of stroboscopic illumination is used. For a frequency of illuminator flashes close to the frequency of vibration of the table, a slow (with the beat frequency) motion of the mark can be observed.

Systematic errors in both reading methods are mainly determined by the quality of the measuring microscope.

The interference method is used in work with piezoelectric vibrostands where the sweep of the vibrating motion does not exceed 1 μ. The essence of this method consists of the following: one of the mirrors of the interferometer optical system is fixed on the vibrating table in such a manner that the vibration of the latter causes a change in the path length travelled by one of the interference beams of light. For certain given amplitude values, the interference bands vanish and the whole field of view assumes a uniform illumination intensity.

The amplitude values for which the disappearance of the interference pattern takes place depend only on the wavelength of the light source. For the usually applied green spectrum line of a mercury lamp with a wavelength of $\lambda = 0.5461\ \mu$, the disappearance of the interference pattern occurs for the amplitude values of vibratory displacement indicated in Table 4.

TABLE 4

Amplitudes of Vibration Displacements for Which the Disappearance of the Interference Pattern Occurs for $\lambda = 0.5461\ \mu$

Number of order of disappearance of the interference pattern	1	2	3	4
Amplitude of vibration displacement (in μ)	0.102	0.24	0.38	0.51

Thus, the interference method permits the establishment of a number of discrete amplitude values of the vibrating table oscillations at which the calibration of accelerometers is performed.

The disadvantage of all the described optical measurement methods is the difficulty in plotting the oscillation curves and also the inconvenience in the taking of readings.

In connection with this, some vibrostands are provided with displacement indicators and electronic equipment which are calibrated by the optical method. With data transmitters having a linear characteristic, it is possible to perform the measurement of amplitudes of $\sim 0.1\ \mu$ with a reading error of $\sim 0.02\ \mu$.

The absolute method of determining the actual acceleration magnitude in calibrating accelerometers according to the results of direct measurements of frequency and amplitude complicates and renders difficult the checking of operational devices to a great extent. This method is applied only in the case where standard accelerometers are not available.

A considerable simplification of calibration and testing can be achieved by the application of control accelerometers (see, for instance, Fig. 2), which are calibrated by the absolute method and which are further used for the calibration and testing of other instruments.

Control accelerometers must have good frequency and amplitude characteristics and also the stability of readings in all frequency ranges and amplitude intervals for which the measurement is performed. Electrodynamic vibrostands are usually provided with induction data transmitters which can be calibrated by the method based on the reciprocity theorem. This method of calibration is connected with considerable methodical and technical difficulties.

The frequency characteristic which can be obtained in calibrating the accelerometers under the conditions of steady-state harmonic oscillations also characterizes the instrument behavior when the acceleration change has an impact character.

However, it is usually preferred to calibrate and test instruments designated for operation under such conditions by creating single acceleration impulses. Moreover, the impulse regime makes it possible to reproduce overloads which exceed the overloads reproducible in vibrostands and attaining 20,000 g and more.

Two forms of devices – ballistic pendulums and falling hammers – are applied for the reproduction of acceleration impulses.

The ballistic pendulum consists of two weights suspended from the base stand. When the calibration is performed, the striking weight is moved through a certain angle and is released by means of an electromagnetic trigger.

When the striking weight hits the target weight, where the data transmitter is affixed, an acceleration impulse appears whose form is very close to a sinusoidal half-wave.

In order to determine the actual peak magnitude of acceleration of the ballistic pendulum, the duration of contact between the striking weight and the target at the moment of impact is measured, as well as the maximum velocity imparted to the pendulum at the target after impact. The measurement of the duration of contact is performed by means of an electronic chronograph connected to a circuit which is closed by pendulums or by means of an electronic counter counting the number of pulses of a standard oscillator at the moment of contact of two pendulums. The velocity of the pendulum and the target is measured by the absolute method (for instance, according to the oscillographic recording of the signal of the photocell which is illuminated by a light beam passing through a grid moving together with the pendulum and the target), or it is calculated by means of the well-known relations of the impact theory. It is more convenient to use the absolute method of measuring the velocity which consists in recording the path sections travelled during equal intervals of time which are given by periodical electrical pulses with a given repetition frequency [8, 9]. The construction of the ballistic pendulum and the method of determining the actual acceleration magnitude are described in more detail in the article by V. P. Neniukov, A. S. Zhmur, and G. D. Liapin, which will be published in one of the following issues of the Journal "Measurement Techniques."

For a ballistic pendulum where the mass of each weight is of the order of 27 kg, the duration of the contact is equal to 0.8-1.0 msec and the maximum acceleration magnitude can attain 500 g. The measurement of the acceleration magnitude is done by a selection of elastic properties of the material of the contact-making parts of the pendulums.

Figure 3 shows a calibration stand of the falling-weight type. It consists of the falling weight, anvil, and means for taking the readings. Three guiding strings serve for securing the correct fall of the weight. The accelerometer to be calibrated is placed on the weight. The magnitude of the acting acceleration is calculated according to the change of momentum at the time of impact and the duration of contact.

The velocity before and after impact is calculated from data obtained in measuring the fall height and the height of rebounce of the weight.

The device shown in Fig. 3 makes it possible to reproduce the peak acceleration magnitudes in the range from 3000 to 15,000 g for a fall height of the weight from 0.3 to 3.5 m, and contact durations from 0.20 to 0.15 m sec.

The falling-weight method permits the creation of accelerations up to 100,000 g, provides a reproducibility within ± 5% and can secure an accuracy in transmitting the acceleration magnitudes within ±10%.

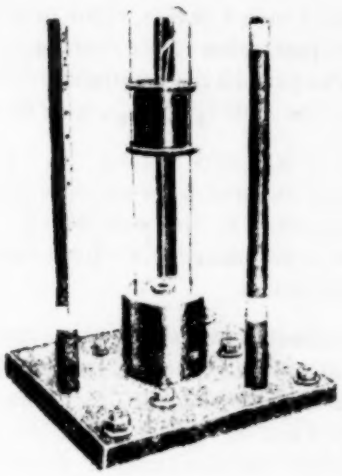

Fig. 3

As in the case of calibrating accelerometers by means of vibrostands, there is a tendency to provide ballistic pendulums and falling weights with built-in control accelerometers which are certified by the absolute method and which are used in calibration and testing of operational accelerometers as standard instruments indicating the actual acceleration magnitude.

The methods of calibration and testing of accelerometers where the static and dynamic operating conditions are reproduced simultaneously can be of considerable interest.

The simplest device for the calibration of accelerometers under the combined operating conditions can be made in the form of a centrifuge with a horizontal rotation axis.

For $\omega = \text{const}$, the acceleration acting on the accelerometer placed on such a centrifuge in such a manner that its operating axis is directed along the radius of the centrifuge can be expressed as

$$a = r\omega^2 + g\sin 2\pi\alpha,$$

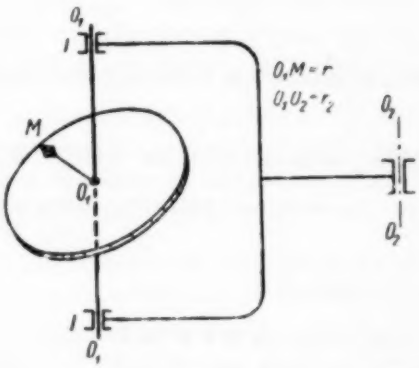

Fig. 4

where α is the angle between the radius passing through the center of gravity of the sensitive element and the horizontal plane.

A great advantage of the described method is the fact that the recording of accelerometer readings in calibration is done on a ready-made scale:

$$a_{max} - a_{min} = 2g.$$

This permits the verification of the linearity of the instrument characteristics according to the constancy of the scale for the acceleration recording which is equal to 2 g for various values of the constant component $r\omega^2$, and the determination of the frequency characteristic without resorting to measurements of frequency and amplitude.

The Coriolis acceleration does not introduce errors of any importance in the calibration and testing results, as it is small in magnitude (due to the smallness of velocities of linear displacements of the sensitive element) and is directed perpendicularly to the working axis of the instrument, which is oriented in the direction of the centrifuge radius.

Even greater possibilities are presented by the application of a device schematically shown in Fig. 4. The disc 1 where the data transmitter M is affixed, rotates about the vertical O_1 axis with a constant angular velocity ω_1; the axis O_2, in turn rotates with a constant angular velocity ω_2 about the vertical O_2 axis. The sensitivity axis of the accelerometer M is directed along the O_1M radius. Neglecting the displacements of the sensitive element of the tested instrument and the velocities of these displacements, considering them as small quantities, we find that the Coriolis acceleration is always directed along the O_1M radius.

It follows from this that the acceleration imparted to the sensitive element of the instrument assumes extremal values at those moments when the radii $O_1O_2 = r_2$ and $O_1M = r_1$ lie on the same line.

The difference between the maximum and minimum values of acceleration is expressed as

$$a_{max} - a_{min} = 2r_2\omega_2^2.$$

Thus, for the determination of the actual acceleration magnitude in calibrating and checking accelerometers on a double centrifuge, it is sufficient to know the angular velocity of the centrifuge rotation about the O_2 axis and distance between the O_1 and O_2 axes, i.e., quantities which can be easily determined with a sufficient accuracy. Then, having measured the difference $a_{max} - a_{min}$ on the graph, we obtain the scale for the determination of the actual acceleration magnitude. In the practical realization of such a device, difficulties arise, which, however, can be overcome by a corresponding choice of construction parameters of the centrifuge, angular velocities and the like. It is of interest that the described method also permits the determination of the phase shift of readings by the recording of pulse signals at the moment when the radii r_1 and r_2 are on the same line.

The method of the "double centrifuge" makes it possible to perform the calibration for various relations of the static and dynamic acceleration components, to investigate systematic errors by means of obtaining equal dynamic components for various angular velocities and distance radii at which the instrument is fixed and — which is most important — to simplify the determination of actual acceleration magnitudes.

The development and improvement of methods and equipment for calibrating and testing of accelerometers lends a great importance to the problem of introducing a single metrological service in this field of measurements. Such a service would not only secure the unity and accuracy of acceleration measurements but it will also provide the possibility of considerably simplifying the methods of calibration and testing with respect to the determination of actual acceleration magnitudes according to indications of standard instruments, which will bring about a considerable saving of time and effort.

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INFORMATION

INTERNATIONAL ORGANIZATION OF LEGISLATIVE METROLOGY

P. P. Arapov

On June 25, 1958, M. Zhakob, President of the International Committee on Legislative Metrology and Doctor of Physico-Mathematical Science, delivered a lecture in the lecture hall of the All-Union Exposition.

All metrologists consider themselves the spiritual sons of the pioneers of the metrological system and place before themselves the goal of developing a system which can serve for all times and for all peoples – in this manner Dr. Zhakob opened his talk.

As far back as the 18th century metrologists were already considering the question of establishing an international metrological organization. On May 20, 1875 an agreement was signed by a metrological convention which had been called with the aim of creating and preserving, by means of an International Bureau of Standards, prototypes of standard units of length and mass. The International Bureau was charged with the duties of preparing and distributing copies of the standards to the various governments.

The creation of a permanent, active bureau staffed by highly qualified specialists and equipped with apparatus of the necessary precision has permitted us to establish a high degree of accuracy in metrological work and in international weights and measures and has also made possible the organization of further investigation of the problems involved.

Representatives of the nations which sponsored the original convention take part in periodic general conferences on weights and measures. In the interval between the conferences the work is carried on by an international committee chosen from amongst the representatives of the above-mentioned nations. The international committee also confers with its consultative committees on matters involving special problems.

The functions of the present national metrological and inspection bureaus are extremely vast and varied. They solve not only purely scientific problems, but also devote a great deal of time to multitudinal problems of a practical and legislative nature which are common to many countries. Every country must carry out difficult and arduous work. At the same time, as a result of this work, rules are established in the various individual countries with respect to the requirements that must be satisfied by scientific apparatus. In some cases it is very difficult to fulfill these requirements, and this imposes a serious hindrance to the use of foreign apparatus. For example, the requirements in one country may specify that brass weights be made with round heads while the neighboring country may manufacture the same type of weight with flat heads; it therefore cannot export its product to another country.

Many questions of mutual interest in the field of legal, applied metrology arise in the various countries for which rational, compatible solutions of the greatest advantage to the user must be found. Together with the solution of problems of general interest concerning the technical regulation of measuring apparatus, the very important question of the best organization of services with respect to legislative metrology arises.

In the 19th century most countries did not have a central bureau capable of performing metrological and testing work with a high degree of precision. The organizations existing at that time, the National Treasury of Arts and Crafts in France and the Main Bureau of Weights and Measures in St. Petersburg, did not devote enough attention to the testing of measuring instruments.

With the start of its functioning in the 19th century the International Bureau of Weights and Measures established the ruling that it was necessary that a connection exist between the national bureau of weights and measures in each country and the International Bureau.

National organizations were created to establish this connection – the Physico-Technical Institute (Germany), the Belgian Metrological Bureau, the National Bureau of Standards (USA), National Physical Laboratory (Great Britain), and others, – the basic problem of these bureaus consisted in insuring uniformity of the national standards of weights and measures with the international standards.

With the development of instrument and apparatus construction it became necessary to create an organization that would establish uniform models. One of the important problems facing the international metrological organization consists in the question of obtaining the greatest possible simplification in the establishment of standards by recognizing the standards tried out in one country and obtained by that country during the process of satisfying its own requirements.

The significant increase in recent times of mass-produced goods makes individual control of the weight and dimensions of the product impossible. Individual control must be replaced by statistical, sample control and for the correct application of this type of control one must work out new methods which should be based upon the recommendations of the international organization of legislative metrology.

The problems facing the contemporary national bureaus of standards are, to a significant degree, the same for all countries, and this underlines the necessity for the creation of an international organization of legislative metrology.

The initiative of the Soviet Union was the decisive influence in the creation of such an organization. At the general conference on weights and measures held in Paris in 1933, the decision was made, based upon the proposal of the Soviet metrological delegates Corresponding Member of the Academy of Sciences of the USSR M. A. Shatelen and Professor L. V. Zalutskii to create a consultative committee on applied metrology. In 1937, an international conference was held in Paris which recognized the very great importance of applied metrology,and therefore, it was considered expedient to create not merely a consultative committee, but rather a permanent organization, working together with the various national organizations dealing with the establishment of basic units and standards and also with the international standards organizations.

At the 1956 convention a motion was carried in which were determined the problems of the international organization of legislative metrology:

1. The establishment of a center for the release of documentation and information about the various national bureaus concerned with the testing and control of measuring instruments, subject to, or capable of being subject to, legislative regulation and similarly about questions regarding the construction, preparation and application of the above-mentioned instruments.

2. The translation and writing of the text of legislative orders regarding measuring instruments and the application of these instruments in the various countries.

3. The determination of the general principles of legislative metrology.

4. To study the problems of legislative metrology of a legal and managerial character possessing a solution of international significance with the aim of unifying metrological methods and regulations.

5. The development of projects regarding typical rules and regulations to be applied to both the measuring instruments and to the use of these instruments.

6. The development of projects regarding the equipment to be used in the testing and control of measuring instruments.

7. The development of the necessary technical characteristics to be fulfilled in the construction of technical instruments, these requirements being subject to the approval of the individual countries – members of the international organization of legislative metrology – and the recommendations of the international body.

8. The development of collaboration between the various bureaus of measures and measuring instruments or other services involved in legislative metrology, countries – members of the international organization of legislative metrology.

At the present time the organization has started to work upon the problems that have been assigned to them. M. Zhakob has expressed his hope for the fruitful and qualified cooperation of the Soviet specialists in the international organization.

CONFERENCE REGARDING THE MEASUREMENT OF HIGH RESISTANCES

In July 1958, the Leningrad Division of the NTO of the instrument manufacturing industry and the Leningrad Press of Scientific-Technical Propoganda sponsored a scientific-technical conference regarding methods and apparatus for the measurement of high electrical resistances. Representatives of more than 50 organizations located in the Leningrad, Moscow, L'vov, Gorky, Tbilisi and Kishinev took part in the conference.

In the introductory remarks Professor D. T. S. (Doctor of Technical Science) E. G. Shramkov made note of the great significance of this conference devoted to the examination of separate, concrete questions arising in electrical measuring technology. The question of the development of methods and apparatus to be used in the measurement of electrical resistance over a wide range of values from the extremely small (of the order of 10^{-6} ohms and less) to high resistances (of the order of 10^{14} ohms) becomes important in connection with the development of the new technology. Several organizations are at present engaged in the development of methods and apparatus for the measurement of such resistances; however, the absence of coordination between them limits the possibility of developing this field of measurement.

Questions connected with the present state of the manufacture of large resistances (nonwire and micro-wire) were discussed at the conference; also examined were the present circuits and the construction of apparatus for the measurement of high resistances and the methods of testing them, methods of protecting high resistance circuits and circuits for, and methods of, constructing null indicators for such circuits.

The reports of B. S. Halperin, V. N. Matveev, A. A. Merkulov, and T. V. Telichkin (VNIIEP) supplied detailed information as to the methods of manufacturing nonwire resistances and micro-wire resistances and their characteristics.

The reports of G. F. Pankratov and T. B. Pozhdestvenski (D. I. Mendeleev All-Union Scientific and Research Metrological Institute) were devoted to the question of more accurate apparatus for the measurement of resistances ranging in magnitude from 10^5 to 10^{14} ohms (with errors of .005 to 0.5%, respectively) and to the measurement of resistances manufactured and used in test equipment.

A series of reports by V. S. Alexander, Danilov, I. A. Bagrov, M. V. Mintz (from the "Vibrator" plant) and A. P. Sivkov were devoted to the new and original design of devices for the measurement of resistances with a range of values from 10^8 to 10^{14} ohms, meggers, 10^9-ohm meters, tera- ohm meters and special bridges.

In the reports of I. V. Butusov and G. F. Pankratov new circuits designed for use in sensitive null-indicators and electrometers for high resistance circuits were discussed.

The report of V. A. Kochan (of the L'vov Polytechnic Institute) was devoted to the general question of suppressing the influence of the current flow resulting from measurements made on circuits containing direct currents; this is especially important in the measurement of high resistances.

In their reports, the members of the conference stressed the present day importance of the questions that were raised, discovered the defects existing in the development of this branch of electrical measurement which consist mainly in the slow development of the production of the new instruments required by industry, the difficulties of obtaining micro-wires and high quality nonwire resistances, and the insufficient information regarding new developments.

G. M. KONDRAT'EV

On August 11th, 1958 there died, in his 72nd year, after a lengthy illness, the Director of the Division of Thermal Measurements of the D. I. Mendeleev All-Union Scientific and Research Metrological Institute, the very deserving worker in science and technology of the R.S.F.S.R., the professor and doctor of engineering science, Georgii Mikhailovich Kondrat'ev.

Since 1924, Georgii Mikhailovich was in charge of the thermometry laboratory and of the low temperature laboratory of the main division of weights and measures. The investigations of Georgii Mikhailovich and his students in the fields of thermometry and metrology have enabled us to establish in the USSR and to put into practice an international temperature scale, insuring the uniformity of temperature measurements made in industry and science. In connection with this research, Georgii Mikhailovich repeatedly took part in the work of the International Committee on Thermometry as the representative of the USSR.

In 1927, without interrupting his work in the VNIIMe, G. M. Kondrat'ev, at the invitation of Academician M. V. Kirpichev, took part in the work of the Governmental Physico-Technical Laboratory. Georgii Mikhailovich's investigations were related to the various questions arising in heat technology and the physics of heat, he developed the basic theory of uniform temperature operation which has found wide application in technical physics and has resulted in the creation of new techniques of thermal measurement and of original methods of thermal computation.

In 1936 appeared G. M. Kondrat'ev's monograph "The Measurement of Thermal Conductivity by the Use of the Methods of Uniform Temperature Operation," which standardized the experimental application of the theory of uniform temperature operation in the various national laboratories.

From the year 1938 until the last days of his life G. M. Kondrat'ev was Professor of Thermal Apparatus at the Leningrad Institute of Precise Mechanics and Optics (LITMO). From 1948 to 1952 he was also the head of the Engineering-Physics Department of the LITMO.

In 1948, Professor G. M. Kondrat'ev was awarded the Stalin prize for the development of new methods and instruments for the measurement of thermal physical parameters. The monograph "Uniform Temperature Operation," published in 1954, presented a generalization of the vast cycle of his work.

The researches of G. M. Kondrat'ev and his students into the creation of new methods for the measurement of the temperature of molten metal in flames were of great practical importance. The methods for the estimation of thermal inertia proposed by G. M. Kondrat'ev were put to use in the various scientific research institutes and were reflected in the National Soviet Standards.

Georgii Mikhailovich often took part in the work of international scientific organizations and lectured in the higher institutions of learning of the G.D.R. Great culture, erudition, a deep knowledge of special problems, his humanity and his wide outlook permitted G. M. Kondrat'ev to be a worthy representative of Soviet science.

For his successful scientific, pedagogical, and social work G. M. Kondrat'ev was awarded the Order of Lenin, the Order of the Red Star, and many medals.

Soviet science has lost with the death of G. M. Kondrat'ev a talented scholar. His students will always cherish in their hearts the glowing image of their friend and teacher.

MATERIAL RECEIVED BY THE EDITORIAL BOARD

CONCERNING THE STRUGGLE AGAINST LOSS OF INFLAMMABLE LUBRICATING MATERIALS

I. G. Entis and V. P. Safonova

As a result of material inspection at more than 50 industrial, structural and road-building machinery plants, we may note the following characteristic defects to be found in the overwhelming majority of establishments in the management of oil supplies.

1. Absence of the necessary measuring facilities (meter-sticks, measuring tanks, oil density-meters, etc.).

2. Irreparable or untrustworthy benzene columns.

3. Complete calibration tables not available for all the reservoirs and cisterns in the storage areas. Errors may be found in many tables. Sometimes the tables are constructed in a form that is inconvenient to use (not in centimeters or not in a finished form, making it necessary to perform supplementary computations, use graphs, etc.). The tables are not always supplemented with the proper blue-prints and information as to the direction of the axes.

4. Improper installation of the reservoirs and cisterns upon their foundations. Many reservoirs are not aligned to be level and are not provided with hermetically sealed covers, breathing and probing pipes, etc.

5. There are an inadequate number of pumps, and in connection with this the workers in the establishment must, in the course of their work, use only one pump and one hose while pumping the various ILM, thus dirtying the pump and hose.

6. Determination of the physical presence of the ILM is made not on the basis of actual measurement, but by means of bookkeeping calculations (book remainders).

Since the listed defects, as was shown by the inspection, are the same for the majority of plants that were investigated, this gives us complete ground to reaffirm that even in the establishments of other branches of industry the same defects exist and that the generating reasons are beyond the region of authority of any particular department.

The workers in the ILM supply depots work mostly "by eye," not because they do not want to perform their duties conscientiously, but because they are not capable of fulfilling the majority of the requirements that are imposed by the departments of governmental supervision, since it turns out that it is not always possible to acquire the necessary equipment and measuring apparatus. The measuring facilities which the plants try to make with their available resources are, in view of these existing causes, rejected by the control branch of the Committee on Standards, Measures and Measuring Devices, since these facilities do not satisfy the technical requirements. Often these requirements are not known to the plant, and if they are, then it is impossible to fulfill the requirements under the conditions existing in the plant. Even the question of the proper control, receipt and delivery of ILM loses its meaning if we do not make sure that ILM supply depots have the proper inventories and equipment; before this question is solved no orders will be effective in changing the state of affairs.

It pays to take a series of measures (even if they be temporary) to relieve the existing situation by creating guidance materials of a practical character for the organization of the administration of medium size ILM plants. In addition to the general instructions these materials should be devoted to questions of the preparation of

(technical conditions, blue-prints, evaluation, etc.) simple means of measurement; for example, in regard to measuring tanks, descriptions and technical characteristics of reservoirs or cisterns and of their auxiliary equipment, also information as to the planning of supply depots, methods of preparing calibrated tables, etc., investigation of the question of lowering the requirements as to the degree of precision required in the means of measurement, since the existing requirements hinder the preparation of an exact inventory by the employees of the plant.

Why, we ask, must measuring sticks which are not more than two meters long be accurate within ± 1 mm, at the same time that the calibration tables are only accurate to the nearest centimeter ? Why must technical measuring devices with a capacity of not more than 10 liters be accurate within ± 0.5% ?

Perhaps we should introduce in the standards a requirement making it obligatory for the manufacturer of ordinary pails to inscribe upon the pails lines indicating the 5 and 10 liter levels. As a temporary measure this will be better than the present situation where a worker in a ILM supply depot is forced to make use of any chance vessel that may be available.

The struggle against losses in the handling of ILM is such a pressing question that it should be solved without delay.

Editor's Note: The questions raised by I. G. Entis and V. P. Safonova are very important and concern actually existing conditions.

The fact that material control in the various establishments is at present conducted by a branch of the Committee on Standards, Measurements and Measuring Devices also serves as testimony to the unsatisfactory state of affairs existing with respect to the measurement of inflammable lubricating materials in the majority of plants, and points out the necessity for more orderly methods of measurement. However, the suggestions put forth by the authors with respect to the requirements regulating the accuracy of measuring devices and their application in the measurements used to determine the ILM inventory are incorrect and contradict the present regulations regarding the need for more orderly methods of verification that are contained in the NSS.

The editor asks the readers to express their opinions regarding the questions touched upon in the article.

SIMPLIFICATION OF THE CALCULATION OF DIAMETERS, GIVEN THE CIRCUMFERENTIAL MEASUREMENT

I. P. Vaganov

During the measurement of large diameters by the method of measuring the circumference with a metallic tape measure, we use the formula $D = \frac{l}{\pi}$, where D is the diameter which we are trying to find in mm, and l is the length of the circumference, obtained by the use of the tape measure, in mm.

Usually, we take the value of π as being equal to 3.14, unjustfiably rejecting the third and subsequent places. This results in an error in the length of the diameter of approximately 2-3 mm, which is obviously not permissible in the measurement of detailed parts (component parts) which must be accurate to the 4th and 5th class of accuracy according to the NSS 2689-54.

As experiments carried through in the Ural Machine Works have shown, it usually takes from 3 to 10 minutes, depending upon the skill of the operator, to divide the circumference by 3.14, and besides the number

of errors and mistakes in writing during the division of many-place numbers reaches up to 30% of the number of all calculations.

We show below a table, in which we have calculated the values of the diameters obtained by dividing the circumferential lengths by π.

l_1	D_1	l_2	D_2	l_3	D_3	l_4	D_4
1000	318.3	100	31.8	10	3.2	0.5	0.3
2000	636.6	200	63 7	20	6.4	1	0.3
3000	954.9	300	95.5	30	9.6	1.5	0.5
4000	1273.2	400	127.3	40	12.7	2	0.6
5000	1591.6	500	159.2	50	15.9	2.5	0.8
6000	1909.9	600	191.0	60	19.1	3	1.0
7000	2228.2	700	222.8	70	22.3	3.5	1.1
8000	2546 5	800	254.7	80	25.5	4	1.3
9000	2864.8	900	286.5	90	28.7	4.5	1.4
10000	3183.1	1000	318.3	100	31.8	5	1.6
11000	3501.4					5.5	1.8
12000	3819.7					6	1.9
13000	4138.0					6.5	2.1
14000	4456.3					7	2.2
15000	4774.7					7.5	2.4
16000	5093.0					8	2.6
17000	5411.3					8.5	2.7
18000	5729 6					9	2.9
19000	6047.9					9.5	3.0
20000	6366.2					10	3.2

In the use of the indicated table for the computation of the diameter, in mm, one need only add the values of the diameters shown next to the circumferential lengths for thousands, hundreds, tens and units.

The new method for the computation of the diameter, by the use of the table, takes on the average only 30-40 seconds, and the errors and mistakes in writing are practically eliminated, since it is much easier to add many-digit numbers than to divide them.

In computing the table, the values of the diameters were rounded off to the tenth of a mm, which, in practice, is entirely adequate for production standards. The total error due to such a rounding off does not exceed ± 0.1 mm.

Example. The circumference of a cylindrical part (detail) when measured with a steel tape was found to be 16837.5 mm.

We now copy from the columns of values shown in the table the values of the diameters corresponding to the circumferential lengths in cm, corresponding to the appropriate number of thousands, hundreds, tens, and units, and add them:

16000	5093.0 mm
800	254.7 »
30	9.6 »
7.5	2.4 »
Diameter=	5359.7 mm

With increasing facility in the use of the above table we see that the table may be reduced to two columns, in one of which we enter the lengths of the circumferences (in thousands of millimeters), and in the other the corresponding diameters. By shifting the decimal point in the first column and rounding off the results to the nearest tenth of a millimeter we can get the diameters corresponding to circumferences whose lengths are equal to hundreds, tens, and units (all measured in mm), all the terms that are required in order to get the required diameter.

In this case the preceeding example may be written in the following form:

16000	5093.0	=5093.0
800.0	254.65	≃ 254.7
30.00	9.549	≃ 9.5
7.000	2.2282	≃ 2.2
0.5000	0.15916	≃ 0.2
Diameter	=5359.586mm	≃5359.6 mm

I. NEW SPECIFICATIONS FOR MEASURES AND MEASURING INSTRUMENTS APPROVED BY THE COMMITTEE

(Registered in September-October, 1958)

New Standards

GOST 8896-58. Jewels for measuring instruments. Sockets. Introduced for the first time.

GOST 8897-58. Jewels for measuring instruments. Agate tips for water meters. Introduced for the first time.

GOST 8898-58. Jewels for measuring instruments. Bearings. Introduced for the first time.

GOST 8899-58. Corundum knife-edge bearings. Introduced for the first time.

New Instructions for Testing Measures and Measuring Instruments

Instruction 76-58 for checking micrometer levels.

Instruction 102-58 for checking contact interferometers with variable graduations from 0.05 to 0.2 μ.

Instruction 171-58 for checking photoelectric pyrometers.

Operating instructions for checking measures and measuring instruments approved by the Technical Administration of the Committee.

Operating instruction No. 173 for checking waveguide attenuators by a substitution method in the range of 0.77-1.8 cm.

II. MEASURES AND MEASURING INSTRUMENTS APPROVED BY THE COMMITTEE AS THE RESULTS OF STATE TESTS AND PASSED FOR USE IN THE USSR

Wattmeters, single-phase, rack-mounted, trade mark D341/2 of the "ZIP" plant, Krasnodar Sovnarkhoz.* State Register No. 1208-58 (incorporating modifications to wattmeters D341 and D341/1 of the same plant, approved in State Register No. 882).

Hydraulic pulsating machines, trade mark GRM-1 of the "ZIM" plant, Krasnodar Sovnarkhoz.* State Register No. 1210-58.

* Sovnarkhoz = Council of National Economy.

Swinging-ram impact machine, trade mark MK-30A of the "ZIM" plant, Krasnodar Sovnarkhoz.* State Register No. 1210-58.

Testing machines, universal, trade mark UM-5 of the "ZIM" plant, Krasnodar Sovnarkhoz.* State Register No. 1211-58.

Moving-iron portable ammeters, trade mark E59, of the "Tochelektropribor" plant, Kiev Sovnarkhoz.* State Register No. 1212-58.

Moving-iron portable voltmeters, trade mark E59, of the "Tochelektropribor" plant, Kiev Sovnarkhoz.* State Register No. 1213-58.

Moving-coil portable ammeters, voltmeters and volt-ammeters, trade mark M502 of the "Tochelektropribor" plant, Kiev Sovnarkhoz.* State Register No. 1214-58.

Ordinary and double dc bridge, trade mark R329 of the "ZIP" plant, Krasnodar Sovnarkhoz.* State Register No. 1215-58.

Portable ohmmeters, trade mark M371 of the "ZIP" plant, Krasnodar Sovnarkhoz.* State Register No. 1216-58.

Moving-coil portable ammeters, trade mark M252. State Register No. 1217-58.

Moving-coil portable voltmeters, trade mark M252. State Register No. 1218-58.

III. MEASURES AND MEASURING INSTRUMENTS EXCLUDED FROM THE STATE REGISTER

Wattmeters D341 and D341/1. State Register No. 882. Only wattmeters trade mark FD-B, FD-R, and FD-BR of the "Elektropul't" plant MEC USSR have been left under this number. The "ZIP" plant of the Krasnodar Sovnarkhoz* has been granted the right to produce for sale wattmeter D341/2.

Moving-coil portable voltmeters, trade mark M502. State Register No. 981.

Portable ohmmeters, trade mark M471. State Register No. 372.

* Sovnarkhoz = Council of National Economy.

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SIGNIFICANCE OF ABBREVIATIONS MOST FREQUENTLY ENCOUNTERED IN SOVIET TECHNICAL PERIODICALS

AN SSSR	*Academy of Sciences, USSR*
FIAN	*Physics Institute, Academy of Sciences USSR*
GITI	*State Scientific and Technical Press*
GITTL	*State Press for Technical and Theoretical Literature*
GOI	*State Optical Institute*
GONTI	*State United Scientific and Technical Press*
Gosenergoizdat	*State Power Press*
Gosfizkhimizdat	*State Physical Chemistry Press*
Gozkhimizdat	*State Chemistry Press*
GOST	*All-Union State Standard*
Goztekhizdat	*State Technical Press*
GTTI	*State Technical and Theoretical Press*
GUPIAE	*State Office for Utilization of Atomic Energy*
IF KhI	*Institute of Physical Chemistry Research*
IFP	*Institute of Physical Problems*
IL	*Foreign Literature Press*
IPF	*Institute of Applied Physics*
IPM	*Institute of Applied Mathematics*
IREA	*Institute of Chemical Reagents*
ISN (Izd. Sov. Nauk)	*Soviet Science Press*
IIaP	*Institute of Nuclear Studies*
Izd	*Press (publishing house)*
KISO	*Solar Research Commission*
LETI	*Leningrad Electrotechnical Institute*
LFTI	*Leningrad Institute of Physics and Technology*
LIM	*Leningrad Institute of Metals*
LITMiO	*Leningrad Institute of Precision Instruments and Optics*
Mashgiz	*State Scientific-Technical Press for Machine Construction Literature*
MATI	*Moscow Aviation Technology Institute*
MGU	*Moscow State University*
Metallurgizdat	*Metallurgy Press*
MOPI	*Moscow Regional Pedagogical Institute*
NIAFIZ	*Scientific Research Association for Physics*
NIFI	*Scientific Research Institute of Physics*
NIIMM	*Scientific Research Institute of Mathematics and Mechanics*
NII ZVUKSZAPIOI	*Scientific Research Institute of Sound Recording*
NIKFI	*Scientific Institute of Motion Picture Photography*
OIIaI	*Joint Institute of Nuclear Studies*
ONTI	*United Scientific and Technical Press*
OTI	*Division of Technical Information*
OTN	*Division of Technical Science*
RIAN	*Radium Institute, Academy of Sciences of the USSR*
SPB	*All-Union Special Planning-Office*
Stroiizdat	*Construction Press*
URALFTI	*Ural Institute of Physics and Technology*

NOTE: Abbreviations not on this list and not explained in the translation have been transliterated, no further information about their significance being available to us.—*Publisher.*

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